HIGH SCHOOL PHYSICAL SCIENCE

PART I

REVISED EDITION

MERCHANT AND FESSENDEN

PRICE, 65 CENTS

THE COPP, CLARK CO. LIMITED
CANADIAN TEXT BOOKS
TORONTO

HIGH SCHOOL

PHYSICAL SCIENCE

PART I

REVISED EDITION

FOR CONTINUATION CLASSES IN PUBLIC SCHOOLS AND LOWER SCHOOL CLASSES IN SECONDARY SCHOOLS

BY

F. W. MERCHANT, M.A., D.PAED.

Principal London Normal School

AND

C. FESSENDEN, M.A.

Principal Collegiate Institute, Peterboro'

TORONTO

THE COPP, CLARK COMPANY, LIMITED

PREFACE.

The High School Physical Science, Part I, has been revised with the purpose of meeting the requirements of the new curriculum.

The method of treatment, which has met with the general approval of teachers of elementary science, has been retained. While the laboratory course is the special feature of the work, an attempt has been made to combine with it a concise and logical outline of the fundamental principles of the subject.

The scientific method and habit of enquiry acquired through laboratory practice is most valuable, but experience shows that the knowledge gained by beginners from laboratory work alone is inaccurate and fragmentary. The effort has been made to meet the situation by giving formulated statements of the more important principles, and, at the same time, by supplying abundant material for original investigation in connection with the development and application of the principles.

Care has been taken to select simple and typical experiments which can be performed by the pupils themselves with inexpensive apparatus.

While most of the experiments are qualitative, a number of simple quantitative determinations are included to lead the student to appreciate the more exact methods of scientific research, and to introduce him to the method of representing results graphically.

A new feature of the work is an Appendix containing suggestions for Manual Training exercises in the construction of some of the more important pieces of apparatus required in the text. Such exercises add value to the course of study in both Manual Training and Physics.

The end gives place and character to Manual Training. The attitude of the student who is constructing a piece of apparatus to be used in an investigation is quite different from that of the one who is being carried through a regular course in a system of graded models which serve no purpose but to give facility in tool manipulations.

In Physics also the student who has constructed his own apparatus in a careful, workmanlike manner, with a due regard for the requirements of the conditions, and has completed his investigation with it, has a grasp of the fundamental principles underlying the experiment, and has acquired a scientific interest and spirit wanting in the student who has worked with ready-made apparatus.

Our thanks are due to Mr. F. W. C. McCutcheon and Mr. F. A. Stuart, of the London Collegiate Institute, for reading the proofsheets, and to Mr. Sugden Pickles, of the London Normal School, for assistance in preparing the drawings and descriptions of the Manual Training exercises.

CONTENTS.

PHYSICAL SCIENCE.

CHAPTER I.

MEASUREMENTS.

I.—General Principles of Measurement.

Experiment 1.

Mark off on the edge of a piece of paper a distance equal to the length of the line A B (Fig. 1).

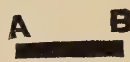


FIG. 1.

Experiment 2.

Draw a line the length of the distance laid off on the edge of the paper.

Which of your senses do you use in determining the equality of the lengths?

Experiment 3.

Lay the edge of the paper with the length A B marked off on it alongside C D and by moving it along thus,

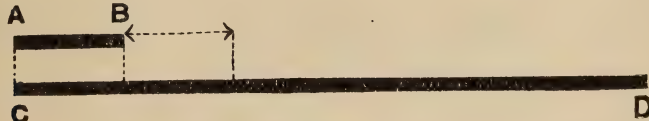


FIG. 2.

find how many times the length of C D contains that of A B.

How many times would the length of C D contain that of A B if A B were (*a*) one-half, (*b*) one-third, (*c*) three-fourths its present length?

Experiment 4.

Determine how many times the length of A contains that of B.

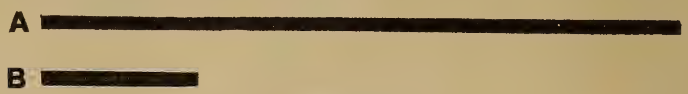


FIG. 3.

Experiment 5.

From Figure 4 the length of A is seen to be three times that of B with a part of A remaining; find by comparing the lines how many times the length of B contains that of the remaining part of A.

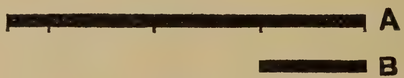


FIG. 4.

How many times then is the length of A that of B?

Experiment 6.

Find how many times the length of your desk contains that of your lead pencil.

1. Quantity.

That which can be expressed as so many times, or such a fraction of, another of the **same kind** is a **quantity**. For example, the length of each line in the above figures is a quantity, because the length of each is a certain number of times that of any other.

2. Measurement.

The measurement of a quantity consists in comparing it with another of the same kind to determine how many times the one is contained in, or how many times it must be taken to make up, one equal to the other.

3. Measure of a Quantity.

The measure of a quantity is the NUMBER expressing how many times the quantity contains another of the same kind assumed as a unit.

The complete expression of a physical quantity, therefore, consists of two parts :

(1.) The **number** indicating how many times the quantity measured contains the unit.

(2.) The **name, symbol,** or **description** of the unit with which the quantity is compared.

For example, we say a certain distance is 10 feet; a surface, 5 square inches; a volume, 8 cubic feet; and a mass, 3 pounds.

1. Give fully your expression of the length of

C D,	Experiment	3	above.
A,	"	4	"
A,	"	5	"
The desk,	"	6	"

2. What is the **measure** of each of the above quantities ?

4. Units.

Since a quantity is measured by comparing it with another of the same kind, **any one quantity** may be used as a unit quantity by which another **like quantity** is measured; but that any system of measurements may be useful for purposes of intercommunication a limited number of units, with which all who are to use them are familiar, must be chosen. Hence it is that most nations legalize systems of units for common use.

5. Standards.

A unit which has been legalized by statute or common use is called a **standard.** Thus in Great Britain the national standard of length is the yard, which is defined by Act of Parliament to be the distance between two parallel lines on two gold studs in a particular bronze bar, the distance being measured when the temperature of the bar is 62° Fahr.

1. Why must the distance between the lines be measured at a set temperature?

2. Why do nations preserve carefully copies cf their standards of measurements?

6. Metric System of Measurements.

By general agreement, what is termed the Metric System of Measurements has been adopted in most countries for scientific use.

It has also been adopted generally on the continent of Europe for the ordinary purposes of commerce.

II.—Metric Measurement of Length.

7. The Unit.

The standard is the **metre.** When adopted it was believed to be the one ten-millionth part of a quarter of the earth's circumference measured from pole to pole through Paris. In reality, it is an arbitrary standard, the distance between two lines on a platino-iridium bar, at the temperature of melting ice.

8. Subdivisions of the Metre.

The metre is subdivided into decimal parts:

Decimetre	(dm.)	Latin *decem*, ten	= $\frac{1}{10}$	or	·1 **metre** (m.)
Centimetre	(cm.)	" *centum*, hundred	= $\frac{1}{100}$	or	·01 **metre**
Millimetre	(mm.)	" *mille*, thousand	= $\frac{1}{1000}$	or	·001 **metre**

That is:

1 metre	=	**10 decimetres**	=	**100 centimetres**	=	**1000 millimetres**
		1 decimetre	=	**10 centimetres**	=	**100 millimetres**
				1 centimetre	=	**10 millimetres**

Or,

1 millimetre = ·1 centimetre = ·01 decimetre = ·001 metre.

9. Multiples of the Metre.

The multiples of the metre are:

Decametre	(Dm.)	Greek	*deka*, ten	=	**10 metres**
Hectometre	(Hm.)	"	*hekaton*, hundred	=	**100 metres**
Kilometre	(Km.)	"	*chilioi*, thousand	=	**1000 metres**

10. Equivalents.

	In Inches.	In Feet.	In Yards.
Metre..........	39·37079	3·2808992	1·0936331
Decimetre......	3·93708	·3280899	·1093633
Centimetre.....	·39371	·032809	·0109363
Millimetre......	·03937	·0032809	·0010936

1 inch = 2·539954 centimetres.
1 foot = 3·0479449 decimetres.
1 yard = ·91438348 metres.
1 mile = 1·609 kilometres.

11. Approximate Values:

Metre = 39·37 inches; a yard and one-tenth.

Centimetre = $\frac{2}{5}$ of an inch.

Inch = 25·4 millimetres.

Kilometre = $\frac{5}{8}$ of a mile.

12. Denominations Most Commonly Used.

The denominations most commonly used are:

Kilometre, used much as we use the mile for measuring long distances.

Metre, used where we use the foot and the yard.

Centimetre, used as the unit of length in scientific physical measurements.

Millimetre, used in measuring short lengths, such as the diameter of a wire, the thickness of a thin sheet, etc.

QUESTIONS.

1. Reduce

Km.	m.	cm.	mm.
5,	3,	5,	2,

to millimetres, to centimetres, to metres, to kilometres.

2. Give a simple rule for changing from one denomination to another.

3. Why is the metric system convenient?

4. How many metres in 125·3 cm., 2·34 mm., 53·65 dm., 8·567 Km.?

5. How many centimetres in 3·45 m., 256 mm., 3·6 Km.?

6. How many kilometres in 3·4 m., 5·6 mm., 37·8 cm.?

7. How many millimetres in 31·6 m., ·85 cm., 9·3 Km.?

8. The measure of a certain length is 35 when the metre is the unit of length, what would be its measure if the centimetre were the unit?

13. Scale.

The method employed in the experiments, pages 1 and 2, of measuring by constantly repeating the standard, would be found to be too slow and too inaccurate for general use. For more rapid and accurate measurements a **scale** or **rule** is used. This consists of a bar, generally wood or steel, on which is laid off the unit, its subdivisions and multiples. The length of the scale and the number of subdivisions of the unit will depend on the purposes for which it is to be used. Metric rules are generally graduated to millimetres. Fig. 5 shows a metric scale one decimetre in length.

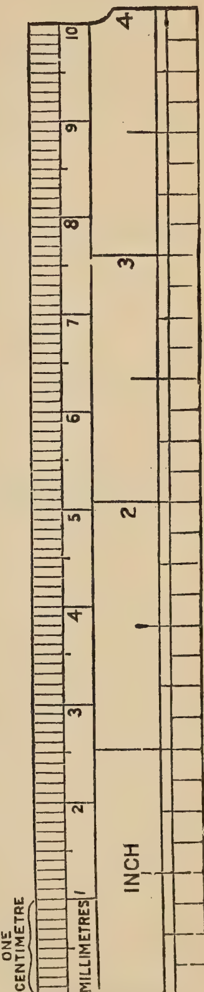


FIG. 5.

14. Method of Using a Scale.

The accuracy of the result in measuring with a scale will depend upon the care with which the length to be measured is compared with the scale.

Since the observer has to depend on his eyesight, he must be careful so to conduct his observations that the coincidence of the marks shall be real and not imaginary.

That no error may arise from the thickness of the scale, thus:

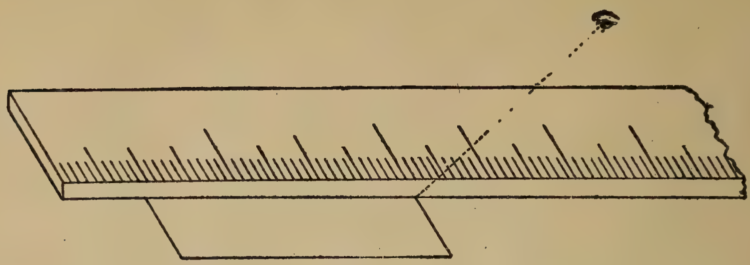


FIG. 6.

it should be placed on edge so that the graduation marks may touch the surface on which the measurement is made. Thus:

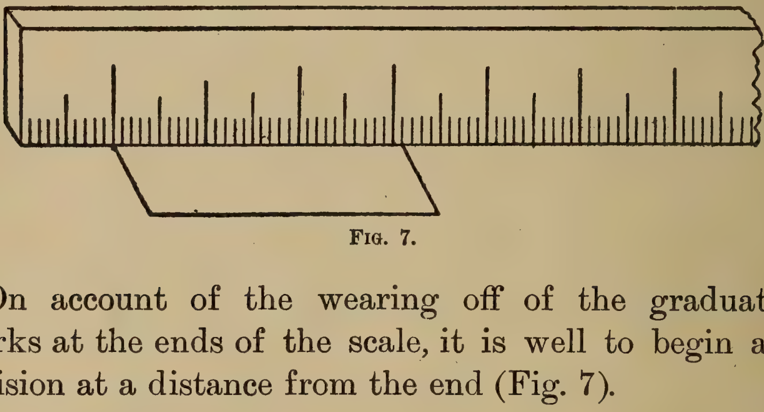


FIG. 7.

On account of the wearing off of the graduation marks at the ends of the scale, it is well to begin at a division at a distance from the end (Fig. 7).

Although metric rules are usually graduated only to millimetres, practice will enable one to estimate to the tenth of a millimetre by an imaginary division of a millimetre into ten equal parts.

Give the lengths of A B, A C and A D (Fig. 8) in centimetres to two decimal places.

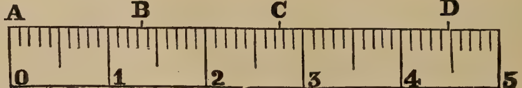


FIG. 8.

15. Experiments in the Measurement of Length with a Scale.

1. Measure the length of this page. Express the result in centimetres.

2. Measure the length of a foot rule in centimetres. From your measurement calculate the equivalent of an inch in centimetres.

3. Measure the distance between the points A and B (Fig. 9).

A X X B

FIG. 9.

Estimate to the tenth of a millimetre.

4. Make a drawing of the top of your laboratory table on a scale of one-tenth.

5. Draw a horizontal line AB 2·7 cm. long, and from B a vertical line BC, 3·6 cm. long. Measure the distance AC.

6. Estimate with your eye the length of your pencil in centimetres. Verify the result by the use of a scale.

Do the same with the lengths of several other objects which you believe to be not more than 15 cm. long.

7. Estimate the length and width of your class-room in metres. Verify the result.

16. Calipers.

To obtain the diameters of cylindrical or spherical bodies **calipers** are usually employed. Figs. 10 and 11 show the common forms of this instrument. When two pairs of points are provided (Fig. 10), the one is used in measuring external, and the other internal diameters. When the instrument has but one pair of points,

internal diameters are measured by making the limbs overlap as shown in Fig. 11.

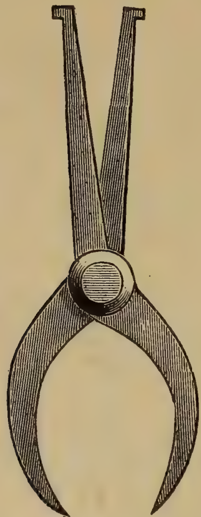


FIG. 10.

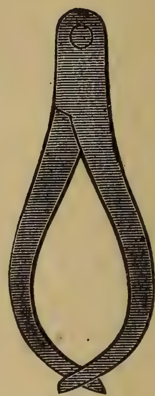


FIG. 11.

The calipers are fitted to the body whose dimensions are to be determined, then removed and the distance between the points measured with a scale.

17. Experiments in Measurement with Calipers.

1. Measure the diameter of a one-cent piece.

2. Measure the diameters of some cylindrical rods.

3. Measure the inside and outside diameters of a tube.

4. Measure the diameter of a small sphere, such as a ball or a large marble.

18. The Vernier.

When greater accuracy is required in measurement with a divided scale than can be obtained directly with the scale by counting the number of whole divisions and estimating with the eye the fractions remaining over, an

auxiliary scale, called a vernier, the object of which is to determine the fractions of divisions, is made to slide on the principal scale.

The vernier is usually graduated so that n divisions of the vernier correspond to $n-1$ division of the scale.

19. Model of a Vernier.

To study the construction and use of the vernier, make a model[1] of a vernier from suggestions given by Fig. 12.

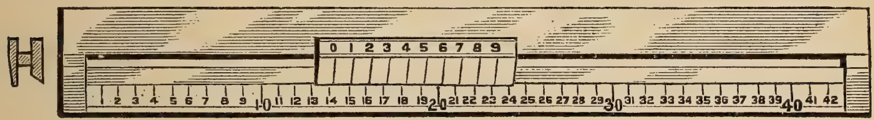


FIG. 12.

The parallel pieces, upon which the vernier slides, are each about 40 × 3 × 1 cm. Graduate the main scale in centimetres, and make the vernier scale 9 cms. long and divide it into 10 equal divisions.

1. How much shorter is a vernier division than a scale division?

2. Make the zero line on the vernier coincide with a definite division line on the scale. How much will the first, second, third, eighth, ninth, and tenth division lines on the vernier fall short of coinciding with the corresponding lines on the scale?

3. If you place the vernier so that the zero division line is (1) 0·1 cm., (2) 0·2 cm., (3) 0·3 cm., (4) 0·6 cm., (5) 0·7 cm., (6) 1· cm., beyond a division line on the scale, what line on the vernier will in each case correspond with a division line on the scale?

4. From your answer to question 3, show how it is possible with the vernier to estimate the fractions of a division which the zero line of the vernier is past a division line on the scale.

5. Set the vernier several times at random, and when the zero line of the vernier does not coincide with a division line on the scale determine the distance that it is beyond the scale division line.

[1] For manual training exercise, see Appendix, page 323.

20. Method of using the Vernier.

In using any instrument with a vernier the first step is to determine to what fraction of the unit the measurement can be made, or in technical terms, to determine the **least count** of the instrument. From the consideration of the case examined above, this is seen to be that fraction of a scale division which a vernier division is shorter than a scale division. This fraction when n divisions of the vernier correspond to $n-1$ divisions of the scale is $\frac{1}{n}$ of a scale division.[1]

If the least count is not marked on the instrument, it can be found as follows:—Make the zero line of the vernier coincide with a division line of the scale, and note what other division lines on the vernier and scale coincide. Count the number both of vernier and scale divisions between these two pairs of coincident lines, and calculate in terms of a scale division the amount which a vernier division is shorter than a scale division.

For example, to determine the least count of the instrument illustrated in Fig. 15, in which the scale is graduated in fiftieths of an inch, slide the vernier along until the zero line of the vernier coincides with a division line of the scale, say No. 5, as shown in the figure. It is then found that No. 20 on the vernier coincides with No. 24 on the scale.

---

[1] A general demonstration of this relationship may be given as follows:—

If s = the length of a scale division

and v = the length of a vernier division

then $nv = (n-1)s$

or $v = \frac{n-1}{n}s$

Therefore $s - v = s - \frac{n-1}{n}s = \frac{1}{n}s$

or a vernier division is shorter than a scale division by $\frac{1}{n}$ of a scale division.

Therefore 20 vernier divisions = 19 scale divisions

or 1 vernier division = $\frac{19}{20}$ of a scale division.

That is, a vernier division is shorter than a scale division by $\frac{1}{20}$ of a scale division,

or the least count = $\frac{1}{20}$ of $\frac{1}{50}$ = $\frac{1}{1000}$ of an inch.

To estimate fractions when the zero line of the vernier does not coincide with a scale division line, observe which vernier division line does most nearly coincide, and the least count multiplied by the number of this line gives the distance which the zero line of the vernier is beyond a division line on the scale.

The vernier is used with an instrument furnished with a scale for taking measurements, and is attached in such a way that the zero on the vernier is coincident with zero on the main scale when the quantity which the instrument is intended to measure is zero; therefore, when the instrument is being used, the position of zero of the vernier on the main scale will always indicate the quantity measured. (Fig. 15.)

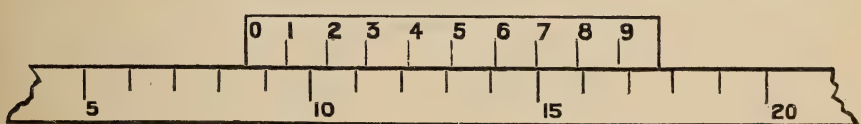


FIG. 13.

1. Give the reading indicated by the vernier in Fig. 13.

2. If you have a barometer reading with a vernier, determine its least count, and take its readings for several days.

3. Give the reading of the barometer, illustrated in Fig. 14, in both English and metric scales.

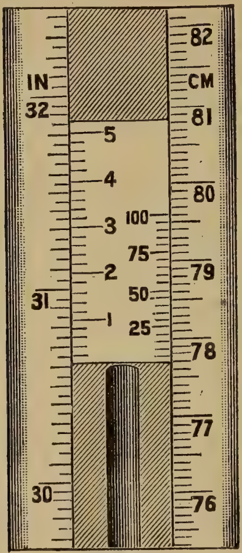


FIG. 14.

21. Vernier Caliper.

Fig. 15 illustrates an instrument for determining short lengths with a considerable degree of accuracy.

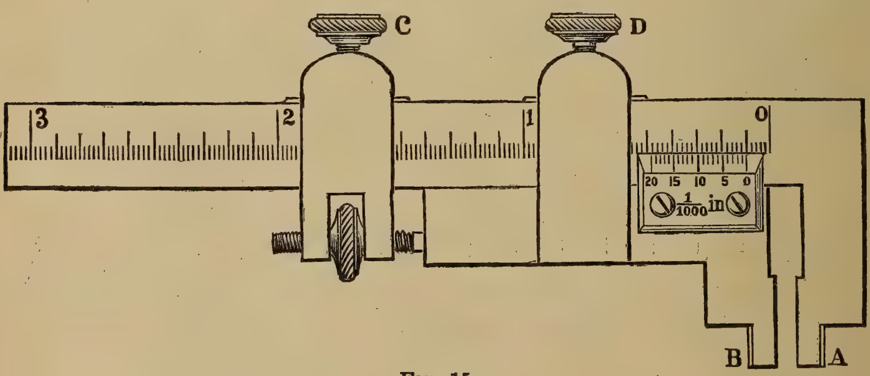


FIG. 15.

It consists of two parallel jaws A and B, the one fixed at the end of a graduated bar and at right angles to it, the other fitted to slide on the bar.

The distance of the jaws apart at any time is read by a vernier attached to the movable jaw.

To use the instrument, place the article whose length is to be determined against the fixed jaw and slide the movable jaw nearly into contact with it, clamp the screw C, and by means of the slow-motion screw E, bring the jaw up until the body is **just held** between the jaws. Clamp the screw D and read the vernier. If no slow-motion screw is provided, the jaw is moved with the hand into **light contact** with the body.

Measure with a vernier caliper

(1) the diameters of several cylindrical rods,

(2) the thicknesses of several sheets of metal,

(3) the diameters of several bicycle balls of different sizes,

(4) the internal and external diameters of tubes, etc.

22. Micrometer Caliper.

The micrometer caliper, Fig. 16, is used to measure small dimensions with great accuracy.

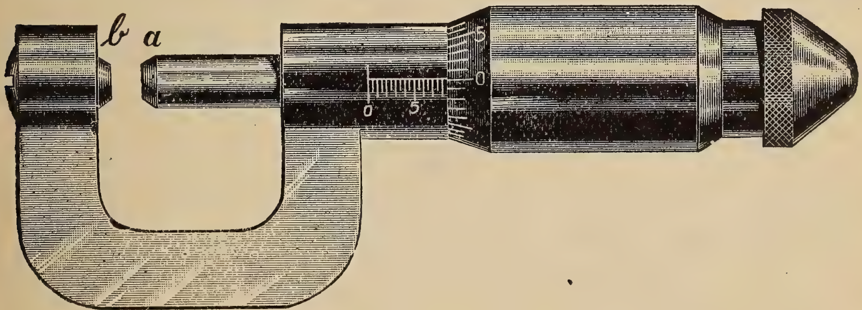


FIG. 16.

It is so constructed that one complete turn of the screw moves the end *a* forward or backward one unit of length, hence the distance *a b* is determined by the number of turns of the screw. The number of complete

turns, or full units of length, is indicated by the linear scale and the fractions of turns, that is, the additional fractions of units, by the circular scale on the head of the screw.

To use the instrument, insert the object to be measured between *a* and *b* and turn the screw up until contact is made. The best calipers have a ratchet motion which enables the contact always to be made with uniform pressure. If a ratchet is provided, continue to turn the head slowly after the contact is made until a given number, say five, clicks is heard; if no ratchet is provided care should be taken **not to turn the screw up too hard**, but to stop when pressure is **just felt.** Read the number of whole units uncovered by the linear scale and add the decimals indicated by the circular scale on the head.

Micrometers measuring in metric units are usually graduated in one of the following ways:

1. The linear scale is divided into millimetres and the circular scale is divided into one hundred divisions.

2. Each division of the linear scale is 0·5 mm. and the circular scale is divided into fifty equal divisions.

When the micrometer measures in inches, the linear scale is usually divided in twenty-fifths of an inch and the circular scale into forty equal divisions.

1. To what fraction can the measurement be made with each of the above micrometers?

2. Measure with the micrometer the objects measured with the vernier caliper and compare measurements.

3. Measure with a micrometer caliper the thickness of a leaf of this book, the diameters of several fine wires, the thicknesses of several thin metal plates, sheets of mica, etc.

III.—Metric Measurement of Surface.

23. Fundamental and Derived Units.

We have seen that in the measurement of length the unit employed is selected arbitrarily. Physical quantities are so related to one another that by choosing certain elementary units all the others may be derived from these in virtue of those relations. The former are called **fundamental,** the latter **derived,** units.

24. Unit of Surface.

From the relation between length and surface, if a unit of length is assumed, a unit of surface may be derived from it. The most convenient unit of surface is a square, a side of which is the unit of length. For example, when the centimetre is taken as the unit of length the square centimetre (sq. cm.) is the unit of surface.

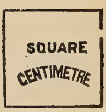


Fig. 17.

25. Measure of Surface.

The measure of any surface is, of course, the number of times the unit surface must be repeated to cover it.

QUESTIONS.

1. If a side of a square is one decimetre, how many surface units will be required to cover it, the unit surface being the square centimetre? Observe Fig. 18.

2. Can the unit of surface be in any other forms than that of a square?

3. Draw on the blackboard a square, a side of which is one metre. By drawing lines as in Fig. 18, divide it into square decimetres. How many are there of them?

4. Draw on paper a square centimetre. By dividing it by lines show how many square millimetres it contains.

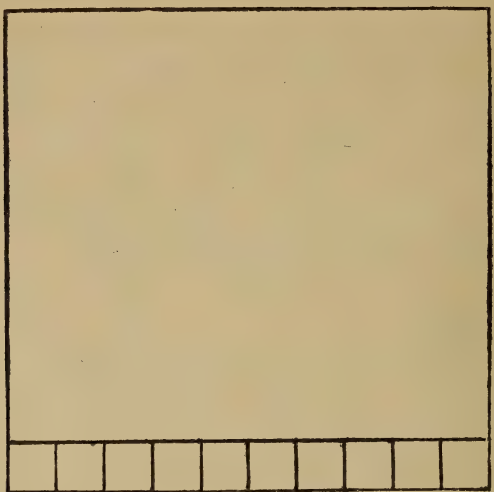


FIG. 18.—SQUARE DECIMETRE (¼ SIZE).

5. From the answers to 3 and 4, fill up the blanks in the following tables:

1 square metre - - = ...sq. dm. = ...sq. cm. = ...sq. mm.

1 square millimetre = ...sq. cm. = ...sq. dm. = ...sq. mm.

6. The surface of a book measures 35·5 sq. cm., what is its measure in sq. metres?

7. A surface measures 5·5 when the square metre is the unit of surface, what will it measure if the square kilometre is the unit?

8. How many square metres in ·01 sq. mm., 1·3 sq. km., 3·5 sq. cm.?

9. How many square centimetres in 25·45 sq. m., 3·01 sq. mm.?

10. The area of a figure is 10 when a decimetre is the unit of length. What is its area when a metre is the unit of length?

26. Approximate Equivalents:

Square centimetre = 0·155 square inches.
Square metre - - = 1·196 square yards.
Square inch - - = 6·452 square centimetres.
Square yard - - = 0·836 square metres.

27. Computation of Surface from Measurements of Linear Dimensions.

The following relations between the measures of surfaces and the measures of their lineal dimensions are assumed.

A **square,** the side of which has a **units of length,** contains a^2 **units of surface.**

A **rectangle,** the sides of which have a and b **units of length,** contains ab **units of area.**

A **triangle,** of which the base is a and the vertical height b **units of length,** contains $\frac{1}{2}ab$ **units of area.**

A **circle,** the radius of which has r **units of length,** contains πr^2 **units of area.**

A **sphere,** whose radius is r **units of length,** has a **surface** containing $4\pi r^2$ **units of area.**

1. Find the surface of a sheet of note-paper in square centimetres.

What would be the side of a square of the same area?

2. By means of a scale and a pair of compasses, draw on paper a triangle of which the sides are 3·9, 5·2 and 6·5 cm. Taking the longest side as base, measure the vertical height and determine the area of the triangle.

3. Determine the surface of one face of a ten-cent piece. Give the result in sq. mm.

4. Find the surface of any ball.

28. Exercise in the Measurement of Surfaces.

To obtain the area of an irregular surface trace its form, either full size or to scale, on cross-section paper, that is, paper divided into a number of small squares by two sets of parallel straight lines drawn at right angles to each other (Fig. 19), and count the number of full squares and estimate the fractions enclosed within the boundary. This will give in terms of the area of a square as a unit the area of the surface.

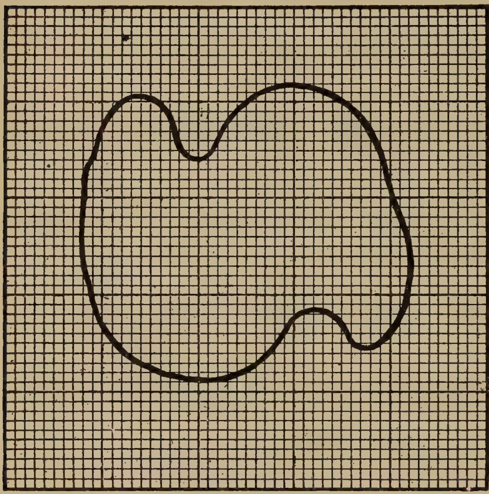


FIG. 19.

The counting of the squares is facilitated by enclosing by darker lines, as shown in the figure, a number of small squares into larger squares. In estimating the fractions, the result will usually be sufficiently accurate to count as a full square each one which has more than half its area within the boundary, and to omit each with less than half its area enclosed.

1. If the paper is ruled in square mm. what is the area of the surface enclosed in Fig. 19?

2. Find the area of a circle 7 cm. in diameter by drawing it on metric cross-section paper. Compare the result with that obtained by the rule, **area** $=\pi r^2$.

3. Trace on cross-section paper an outline map, say that of your municipality, count the number of enclosed squares, and, noting the size of the squares and the scale of the map, compute the area.

IV.—Metric Measurement of Volume.

The method of measuring **volume** is essentially the same as that employed in measuring **length** or **surface.** A volume is measured by comparing it with some other **quantity of the same kind**, that is with some other **volume**, taken as a unit. Its measure is the number of times it contains this volume, just as the measure of a certain **length** is the number of times it contains some **unit length**, and the measure of a **surface** the number of times it contains a **unit surface**.

29. Unit of Volume.

From the relation between length and volume, if a unit of length is assumed, a unit of volume may be derived from it. The most convenient is a volume in the form of a cube, an edge of which is the unit of length. For example, when the unit of length is the centimetre, the unit of volume is the cubic centimetre (c.cm.)

QUESTIONS.

1. Is the unit of volume a **fundamental** or a **derived** unit?

2. Can the unit of volume be in any other form than that of a cube?

3. Why is a cube a convenient form?

4. Dissected Litre Block.

To study the relations among the metric units of volume, make a dissected litre block[1] from the suggestions given in Fig. 20. The enclosed box is $10 \times 10 \times 9$ cm. The rectangular piece is $10 \times 9 \times 1$ cm. The rod

---

[1] For manual training exercise, see Appendix, page 323.

is 1 x 1 x 9 cm., and cube, edge 1 cm. These parts are made to fit together with pins to form a cube, edge one decimetre. A **litre** is a cubic decimetre.

Examine the block and determine the number of cubic centimetres in a cubic decimetre.

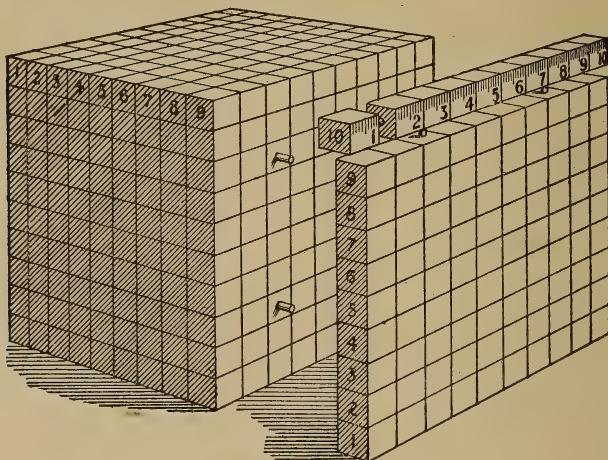


FIG. 20.

5. Construct diagrams to show (*a*) the number of cubic decimetres in a cubic metre, (*b*) the number of cubic millimetres in a cubic centimetre.

6. From the answers to 4 and 5 fill in the blanks in the following table:

1 **cubic metre** = ...c.dm. = ...c.cm. = ...c.mm.
1 **cubic millimetre** = ... c.cm. = ...c.dm. = ...c.m.

7. How many cubic centimetres in 531·56 c.m., 235·78 c.mm. ?

8. If the measure of a volume is 5324·56 when the cubic centimetre is the unit of volume, what would be its measure if the cubic metre were the unit ?

9. How many cubic millimetres in 50·23 c.cm., 32·75 c.m. ?

10. What is the **measure** of a litre when (*a*) 5 cm. is the unit of length, (*b*) when a cubic metre is the unit of volume ?

30. Approximate Values.

Cubic centimetre	=	0·061 cubic inches = 0·034 fluid ounces.
Cubic metre	=	1·308 cubic yards.
Litre	=	1·761 pints.
Cubic inch	=	16·387 cubic centimetres.
Cubic yard	=	0·764 cubic metres.
Fluid ounce	=	29·57 cubic centimetres.
Quart	=	1·136 litres.

31. Computation of Volume from Measurements of Linear Dimensions.

The following relations between the measures of solids and the measures of their lineal dimensions are assumed :

A **cube,** the edge of which has a **units of length,** contains a^3 **units of volume.**

A **rectangular bar,** of which the edges are respectively a, b and c **units of length,** contains abc **units of volume.**

A **cylinder,** the height and radius of which have h and r **units of length** respectively, contains $\pi r^2 h$ **units of volume.**

A **sphere,** the radius of which has r **units of length,** contains $\frac{4}{3}\pi r^3$ **units of volume.**

1. Find the internal volume of a crayon box in (a) litres, (b) gallons.

2. Determine, by measuring its depth and its diameter, the capacity of any cylindrical vessel. Give the result in cubic centimetres.

3. Find the volume of any spherical ball.

4. Measure the length and the internal and external diameters of a tube and compute the amount of metal in it.

32. Experiments in Measuring Volume.

The volume of a liquid can be obtained directly by means of measuring vessels graduated to contain a certain number of units of volume. Fig. 21 shows several forms of these vessels.

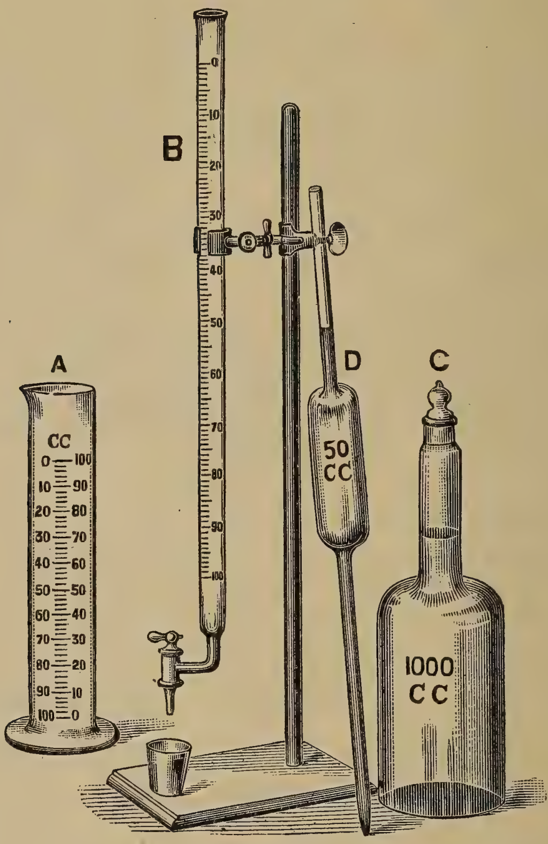


FIG. 21.

A is a form of **graduate** used to measure a range of varying volumes when no great accuracy is required. Each graduation line on the side indicates the volume of the liquid contained in the vessel between its level and the bottom.

The long, narrow tube B with a scale on one side and fitted with a tap or pinch-cock at the lower end, is called a **burette.** It is used to measure volumes with considerable accuracy. The graduations usually read downwards to indicate the volume of a liquid run off through the tap.

C is a **measuring flask** with a narrow neck made to contain, when filled to a mark engraved on the neck, a definite volume of a liquid, usually a litre, half-litre or a quarter-litre.

The form D is a **pipette.** It is useful for transferring a fixed volume of a liquid from one vessel to another.

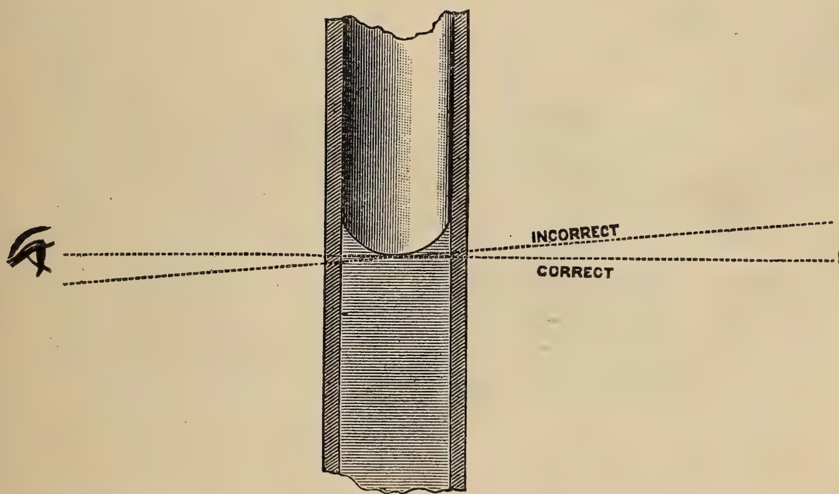


FIG. 22.

In using a burette or a graduate, be careful to see

(1) That it is held in a vertical position;

(2) That the reading is taken from the centre of the curved surface as seen when the eye is **level** with it. (Fig. 22.)

1. Run 10·5 c.cm. of water from a burette into a graduate. Does the graduate indicate the same volume?

2. Measure the internal volume of a small bottle by filling it with water and measuring the volume of the water (*a*) with a burette, (*b*) with a graduate. Compare the results.

3. Measure with a burette 100 c.cm. of water, and pour it into a small Florence flask that will just contain it. Mark on the neck of the flask the position of the surface of the water.

4. Use the flask prepared in Experiment 3 to make (*a*) a 500 c.cm. flask, (*b*) a litre flask.

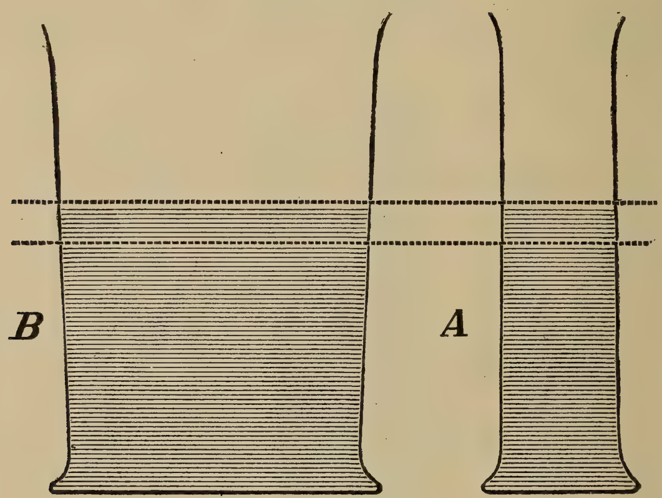


FIG. 23.

5. Determine the volume of water required to raise by one centimetre, the levels of water contained in a beaker and in a test-tube. (Fig. 23.)

(1) What is the ratio of the area of the surface of the water in the beaker to the area of the surface of the water in the tube?

(2) What would be the area of the surface of the water in a tube, if one centimetre **in length** on a tube indicated 1 c.cm. **of volume?**

(3) With which can the volume of a liquid be measured with the greater accuracy, a narrow graduated vessel like A (Fig. 23), or a wide one like B? Why?

6. Obtain the volume of an irregular solid, for example a pebble, by placing it in a narrow graduated tube containing water, and noting the volume of water it displaces.

How could you obtain by a similar method the volume of a solid lighter than water?

CHAPTER II.

MATTER.

I.—General Properties.

Our knowledge of the phenomena of the external world is derived through the medium of our senses. An extended study of these phenomena leads to the belief that the sensible universe is made up of but two classes of existences or entities, **matter** and **energy**.

It is difficult to give precise definitions of these terms. Energy will be treated of in another chapter.

While we may describe matter by its properties, which, in general, are the various ways in which it appeals to our senses, we cannot define absolutely its essential nature.

The following are some of the more obvious of the properties which are common to all forms of matter.

1. Extension, or the Property in Virtue of which Matter Occupies Space.

It is evident that wood, iron, water and other solid and liquid bodies occupy space.

Does a gas, like air, occupy space?

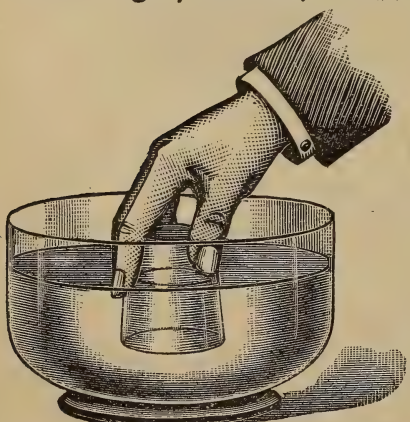


FIG. 24.

Experiment 1.

To answer this question, take a clear glass tumbler filled with air, and, holding it in a vertical position with bottom upwards, push it down into water. (Fig. 24.)

1. Does the water fill the tumbler?

2. Does the air occupy space?

2. Impenetrability.

The last experiment shows not only that the air occupies a certain amount of space within the tumbler, but that it occupies this space to the exclusion of the water. The experiment, therefore, illustrates another property of matter, namely, **impenetrability,** which means that **two portions of matter cannot occupy the same space at the same time.**

Experiment 2.

Vary experiment 1, above, by inserting a bent glass tube into the tumbler, as shown in Fig. 25, before pushing it down into the water.

1. What difference in the behavior of the water within the tumbler is observed?

2. How do you account for the change?

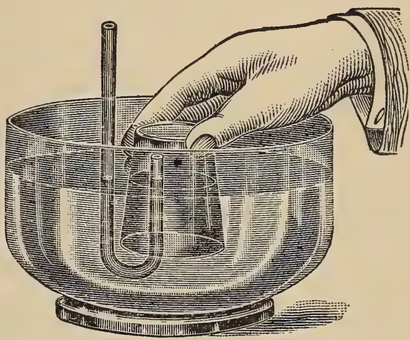


Fig. 25.

Experiment 3.

Insert a perforated cork,[1] through which passes a thistle-tube and a delivery tube, into a bottle (Fig. 26), and pour water into the thistle-tube, alternately closing and opening the delivery-tube with the finger.

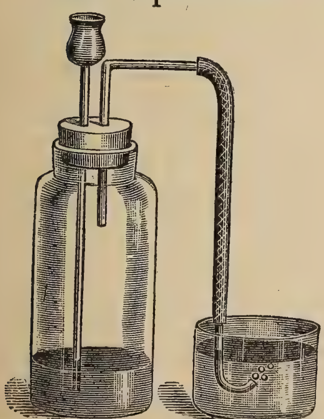


Fig. 26.

Describe and explain the action of the water within the thistle-tube when the delivery-tube is (*a*) closed, (*b*) open.

Insert the outer end of the delivery-tube into water held in another vessel and pour water into the thistle-tube.

[1] When possible, the perforated corks used in all such experiments should be rubber. If rubber corks are not available, the ordinary corks should be perforated with a sharp cork-borer and soaked in melted paraffin.

Describe and explain what takes place in (*a*) the bottle, (*b*) the water held in the other vessel.

3. Porosity.

Does impenetrability preclude interpenetration of matter?

Experiment 4.

Drop a piece of dry pumice stone into a measured volume of water. Observe it for a minute or two, take it out and measure the volume of the water remaining.

1. Has the pumice stone increased perceptibly in volume?

2. Has any of the water disappeared? If so, where is the water which has disappeared?

Experiment 5.

Place 10 c.cm. of salt into 100 c.cm. of water and stir until the salt has all disappeared.

1. What is the volume of the mixture?

2. What has become of the salt?

In the case of the pumice stone it is evident that the water which disappeared fills the pores which can be seen within the sponge-like mass of the stone. We can account for the disappearance of the salt in the water only on the supposition that the water also is porous, although the pores are invisible.

All our experiences with matter lead us to believe that **all matter,** whether it contains visible pores or not, is nevertheless, more or less, **porous in structure.** This characteristic of the structure of matter is called **Porosity.**

In all cases where one form of matter apparently interpenetrates another, it but occupies the spaces or pores within its mass.

What occupied the pores within the pumice stone before the water entered? What evidence did you have of this

4. Divisibility; or that Property which renders Matter capable of being divided.

Can matter be indefinitely divided?

Experiment 6.

Drop a crystal of potassium permanganate or a drop of analine copying ink into a litre of water and stir for a few minutes.

1. Describe what takes place.

2. How do you account for the transmission of the color through the water?

Pour the mixture into three or four times its volume of clear water contained in a glass vessel.

Is the water all tinged with color?

Explain the following :—

(*a*) When an odorous body, such as musk, is brought into a large room the odor can be detected in all parts of the room.

(*b*) It is possible to detect the flavor of strychnine in water which contains but $\frac{1}{1750000}$ of a grain of the drug to one grain of water.

Experiments similar to the above tend to show that there is no **practical** limit to the divisibility of matter. We shall discuss later a **theoretical** limit.

5. Inertia.

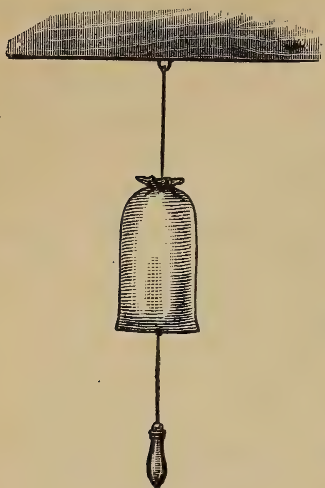


FIG. 27.

Experiment 7.

Suspend a small bag filled with sand (Fig. 27) by a thread not much stronger than will sustain the load. By means of a similar thread, attach a small bar or handle to the lower part of the bag. Grasp the bar and pull steadily downwards until one of the threads breaks.

Which thread breaks? Why should this thread rather than the other break?

Now suspend the bag and bar as before. Again grasp the bar, and, with a quick jerk, pull suddenly downward.

Which thread now breaks?

Experiment 8.

Suspend a heavy weight,[1] say 10 pounds, by a stout cord 15 or 20 inches long. Tie a fine thread around the middle of the weight and give it a sudden pull sideways.

What change takes place in the condition of (*a*) the thread, (*b*) the weight?

Tie the thread again around the weight and, by means of a series of well-timed, gentle pulls, set the weight swinging to-and-fro. When it is going through a fairly wide arc, try to stop the weight at its lowest position by suddenly tightening the thread when it reaches this point.

Describe the action of both weight and thread.

---

[1] The iron balls used as safety-valve weights answer well for many such purposes in the laboratory. They can be had at most foundries.

The weight when at rest exhibits a tendency to "hang back," or remain at rest when pulled suddenly in any direction, and when in motion exhibits a tendency to remain also in this condition.

This **tendency**, which is a universal property of matter, **to retain its condition of rest or motion** is called **Inertia**. If a body at rest is to be set in motion, the motion must be imparted to it by some other body in motion; and if a body is already in motion, it can be stopped only by some influence outside of itself.

Experiment 9.

Lay a card over the mouth of a bottle (Fig. 28), and place a small coin on the card above the opening. Suddenly drive the card off by striking it with the finger.

Fig. 28.

What becomes of the coin? Explain the reason.

Explain each of the following:

(*a*) One from a number of checkers piled up in a column may be knocked out of the column by giving it a sharp blow without overturning the column.

(*b*) If a needle is stuck into each end of a broomstick and the stick supported by resting the needles on glass goblets, as shown in Fig. 29, the stick may be broken by striking it at the middle a quick, strong blow with a heavy iron rod without breaking the needles or goblets. Try the experiment.

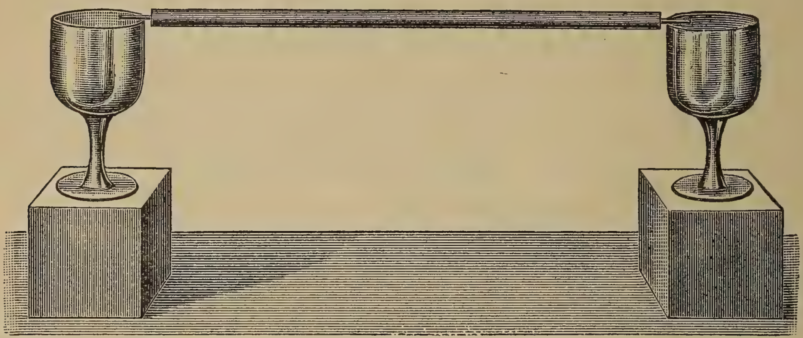


FIG. 29.

(*c*) Persons in a rapidly moving car are usually thrown forward if the breaks are suddenly applied with full force.

(*d*) A rider is liable to be unhorsed if the horse shies or stops suddenly.

(*e*) A person who steps from a rapidly moving car is in danger of being thrown to the ground. It is less dangerous to step out in the direction in which the car is moving than in the opposite direction.

(*f*) A circus rider can pass over a rope extended across the ring and regain his footing on his horse by leaping straight up when he comes to the rope.

(*g*) The outside bank is worn away when a river takes a sharp turn.

(*h*) It is an advantage to run before a leap. It is safest to skate quickly over thin ice.

6. Substance, Body, Mass.

Our most superficial observations show us that matter differs in kind and varies in quantity. Water differs from stone, sugar from salt, and air from ammonia.

A **definite kind** of matter is called a **substance,** and a **definite portion** of matter, **a body.**

The quantity of matter in a body is called its mass.

II.—States of Matter.

7. What Characteristic Properties Distinguish the Solid State of Matter from the Fluid?

Experiment 1.

Take any solid body, such as a piece of wood or iron, lift it and place it on the table.

1. Does the whole move when a part moves?

2. Is its shape changed?

3. What is necessary to change its shape?

Experiment 2.

Put your fingers into a vessel containing water and try to lift the water out. With a spoon dip the water out of one vessel and place it in another of a different shape. Pour water on a horizontal surface. Try to grasp a handful of air.

1. Is the whole of the water lifted out when a part is raised?

2. Has it a definite shape of its own?

3. What shape does it take?

4. Can you lift a piece of air and carry it from one point to another? Has any portion of air a shape of its own?

Water and air belong to the class of bodies known as Fluids.

A solid is a body that possesses rigidity, that is, the power to resist change of shape.

A fluid is a body which possesses no rigidity whatever, but which is deformed by the action of any force, however small.

8. What Characteristic Properties Distinguish Liquid from Gaseous Fluids?

Experiment 3.

Take a glass tube (Fig. 30) closed at one end, fill it nearly full of water or any other liquid, insert a piston and push in on it.

Is there any change in the volume of the liquid?

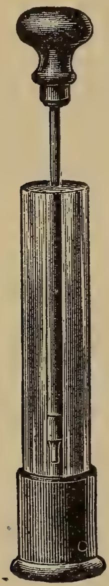


FIG. 30.

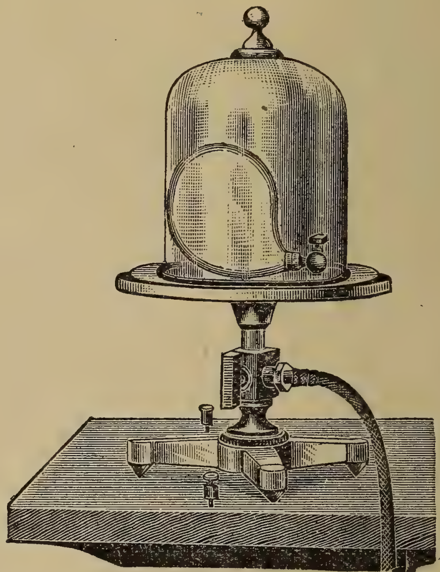


FIG. 31.

Experiment 4.

Repeat Experiment 3, having the tube filled with air instead of water.

1. What change takes place in the volume of the air?
2. What causes the change?

Experiment 5.

Place an elastic rubber balloon partially filled with air under the receiver of an air pump (Fig. 31). Exhaust the air from the receiver.

1. What change in the volume of the air in the balloon takes place?

2. How did removing the air from the receiver affect the pressure to which the balloon is subjected?

3. What caused the change in the volume of the air in the balloon?

On the basis of compressibility and expansibility, fluids are divided into two classes, **liquids** and **gases**.

A liquid is a highly incompressible fluid, that is, it is a body which possesses a definite volume but no definite shape, moulding itself into the shape of the containing vessel.

A gas is a compressible and expansible fluid, that is, it is a body which possesses neither definite shape nor definite volume, taking not only the shape but also the volume of the containing vessel.

9. How Does a Powder, like Flour or Sand, Differ from a Liquid?

Experiment 6.

To answer this question, pour some of it on a horizontal table.

Push a pencil down into (*a*) water, (*b*) a powder, and withdraw it.

Describe the difference in the behavior of the water and the powder under the above conditions.

Look at the powder on the table through a magnifying glass.

What appearance has it? How does it differ from, and how resemble, a heap of stones?

III.—Constitution of Matter—Molecular Theory.

10. Fact—Theory.

Experiments lead to the establishing of facts. To explain these facts theories are proposed. A theory is an imagined cause which is sufficient to account for a fact. It should be clearly distinguished from the fact of which it is the supposed explanation. It is not the statement of anything established by investigation, but simply a possible or probable explanation of some observed phenomenon. It may or may not be true. The simpler it is, and the greater the variety of phenomena it is capable of explaining, the greater is the probability of its truth.

11. Molecular Theory.

We have shown that matter exists in different states.

The molecular theory of the constitution of matter is offered as an explanation of this and numerous other facts connected with matter. It may be thus stated:

1. *Matter is not continuous, but is built up of extremely minute*[1] *parts, called* **molecules.**

2. *The molecule is the smallest quantity of any substance which can exhibit the properties by which that substance is identified.*

3. *All molecules of the same substance are alike, but those of different substances are different.*

4. *Molecules are not in permanent contact with one another, but are separated by intermolecular spaces which are often large as compared with the molecules themselves.*

---

[1] Although molecules are so small that microscopes of the highest power cannot detect them yet they are not beyond the limits of calculation. According to Lord Kelvin's estimate there are not more than 10^9, nor less than $5 (10)^6$, molecules per linear centimetre in ordinary liquids or solids.

5. The molecules have a rapid to-and-fro motion and are constantly striking their neighbors and rebounding from them, thus keeping open the spaces between them.

12. Molecular Conditions of the States of Matter.

In each of the states the molecules are in active vibratory, or to-and-fro, motion.

In solids the molecules are not supposed to move from place to place through the body, but each has, relatively to the others, a definite position in which it moves.

In fluids the molecules are free to move from any one part of the mass to any other, and in consequence liquids and gases take easily the shapes of the vessels in which they are placed.

In liquids the molecules are not so free to move as in gases. They simply glide around among one another, encountering and jostling those near them; while in gases, since the intermolecular spaces are larger, they have periods of free motion and appear to be in a continual state of repulsion. Hence gases are compressible and expansible, while liquids are practically incompressible.

CHAPTER III.

MOTION.

1. Position.

1. Describe the position of some object in your room.

2. Can you describe the position without reference to some other point?

3. Can you do so without making use of distance and direction?

4. Describe accurately and in several ways the position of the point A on this page.

×A

From considerations such as the foregoing it becomes evident that we cannot even think of the **absolute** position of a body (*i.e.*, of its position without reference to any other body). Hence we say that position is only **relative**. We also see that position involves the simple notions of **distance** and **direction**. The position of a point P is determined when its **distance** and its **direction** from some other point, taken as a point of reference, are known.

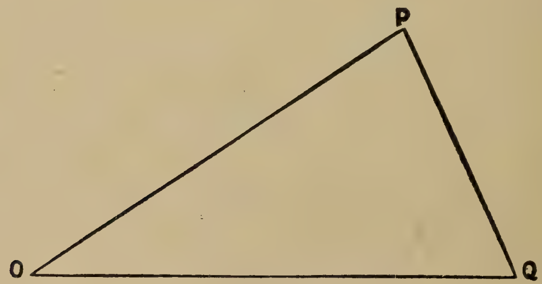


Fig. 32.

The line OP (Fig. 32) represents by its length and its direction the position of the point P with reference to the

point O. Similarly, QP represents the position of the point P with reference to the point Q. That is, P has one position with reference to O, and another with reference to Q. In the same way, Q has one position, represented by the line OQ, with reference to O, and another, represented by the line PQ, with reference to P.

2. Motion.

1. What do you mean by saying that a railway train is in motion?

2. What would you mean by saying that one passenger in that train is moving about while another passenger is at rest?

3. Are the seats in the railway coach moving? With respect to what are the seats moving?

4. With respect to what are they at rest? Is the earth at rest?

From the answers to the above questions it appears that **motion, like position, is relative.** We say that **A is moving relatively to B when the position of A with respect to B is changing continuously.**

We often speak of the motion of one body without mentioning another body. In such a case the body not mentioned is easily understood. Give examples of this.

If the position of a point P with respect to a point of reference remains unchanged for a given time, P is said to be at rest with respect to this point of reference during that time; but, during the same time, the point P may be in motion with respect to another point of reference. A seat in a railway carriage in motion is at rest with respect to another seat in the same carriage, but in motion with respect to any object which has not the same motion as the carriage.

Two points are at rest relatively to each other when their motions are identical.

3. Velocity.

Often we have occasion to consider not only the total change of position which a body undergoes, but also the length of time during which this change of position takes place.

1. A train moves from Montreal to Toronto, 333 miles, in nine hours. What is its average speed in (*a*) miles per hour, (*b*) yards per minute, (*c*) feet per second ?

2. A particle moves a distance of 16·48 m. in four seconds. What is its average speed in (*a*) metres per minute, (*b*) centimetres per second ?

In answering the above questions we have been determining in various units the **average number of units of space** traversed by the bodies in a **unit time,** or the **time-rate of the motion.**

The time-rate of motion of a body, without reference to its direction, is called **speed.** Thus we speak of the speed of a horse or of a railway train without reference to direction of motion.

The time-rate of motion along a definite line, whose direction is given, is called **velocity.** In other words, the term velocity includes the idea of rate of motion and that of its direction.

4. Uniform and Variable Velocity.

Does the tip of the minute-hand of a clock pass over equal divisions on the dial in equal intervals of time ?

Does a train in setting out from a station pass over equal distances in successive seconds? Does it do so in nearing a station at which it has to stop?

When a body passes over equal spaces in successive equal intervals of time, its motion is said to be **uniform.** When it traverses unequal spaces in successive equal intervals, its motion is **variable.**

Give other examples of uniform and variable motion.

5. Average Velocity.

When a body is moving with a variable velocity, it is evident that its average velocity for any given interval of time equals the uniform velocity of another body which has an equal total displacement in the interval.

Hence the **measure of the average velocity during a given interval is obtained by dividing the measure of the distance traversed during that interval by the measure of the interval.**

Experiment 1.—Determination of Average Velocity.

Prepare a straight, stiff plank about three metres long. On one side fasten lengthwise two narrow strips (as in Fig. 33).

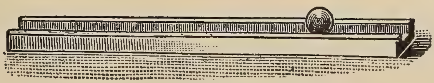


FIG. 33.

Place the plank on a table with this side upward, and with one end enough higher than the other to cause a sphere (a large glass marble answers well) to roll down the channel between the two strips readily but not too rapidly.

Adjust a metronome[1] (Fig. 34) to tick seconds, and set the sphere free at the instant a tick is heard. Mark with a piece of chalk its position at each successive tick.

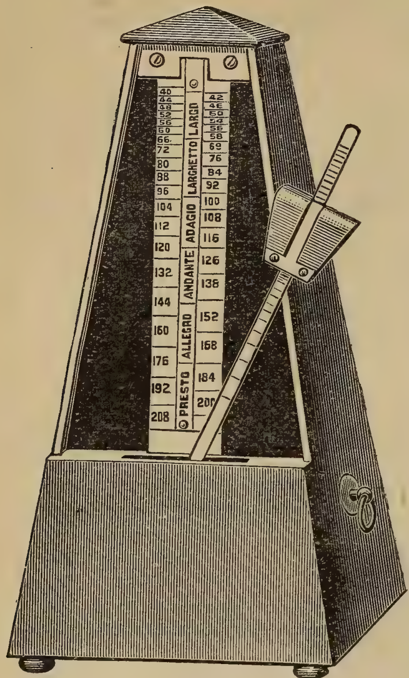


FIG. 34.

With a graduated ruler or tape determine the distance traversed by the marble during the following intervals: (*a*) 1st second, (*b*) 2nd second, (*c*) 3rd second, (*d*) 1st and 2nd seconds, (*e*) 2nd and 3rd seconds, (*f*) 1st, 2nd and 3rd seconds, etc.

1. Find the average speed during each of the foregoing intervals.

2. Carefully compare the average speeds in the first three cases.

3. Describe in your own way, as fully as you can, the motion of the marble along the plank.

4. A point has displacements of 3 feet, 4 feet, 5 feet, and 6 feet in four consecutive seconds. What is its average velocity?

5. A point has displacements of 9 cm., 10 cm., 11 cm., and 12 cm. in four consecutive seconds. Find its average velocity (1) for the four seconds, (2) for the first three seconds, (3) for the last three seconds.

6. A point has displacements of 2 feet, 6 feet, 10 feet, 14 feet, and 18 feet in five consecutive seconds. Show that the average velocities for the five seconds, the middle second, and the three middle seconds, are all equal.

[1] A metronome is a most useful piece of apparatus in the laboratory; but if it is not available, a simple pendulum, made by suspending a weight by a wire or cord, may be used in such experiments. If the distance from the point of suspension to the centre of the weight is 993 millimetres, the pendulum will swing in a period of one second approximately.

6. Uniformly Increasing or Decreasing Velocity.

If the above experiment is performed with care it will be found that the difference between the average velocities during the first and second seconds is approximately the same as the differences between the average velocities during the second and third seconds. That is the velocity of the ball varies by **increasing uniformly.**

7. Acceleration.

If the motion of a particle is changing, the particle is said to be accelerated positively or negatively, according as its velocity is increasing or diminishing.

1. At one instant the velocity of a railway train is 40 miles per hour, 80 minutes later its velocity is 30 miles per hour. How much has its velocity changed during the whole interval?

2. How much, on the average, during each minute?

3. How much during one hour?

4. Describe fully the change per minute in the velocity of this train.

5. Describe the change in the velocity of the marble as it rolls down the plank in the experiment above.

Rate of change of velocity is called acceleration.

1. In answering question 4 above, what unit of acceleration did you use?

2. Answer the same question, using another unit.

3. Is your unit fundamental or derived?

4. If the latter, from what is it derived?

8. Uniform Acceleration.

If the velocity of a body is increasing or decreasing by equal amounts in all equal intervals of time, its **acceleration** is said to be **uniform.**

1. A point is moving with a uniform acceleration of 10 units of velocity each second. What velocity will it acquire in a minute?

2. A point moving with a uniform acceleration acquires a velocity of 60 feet per second in ten minutes. What is the increase in its velocity per minute?

3. A particle moving with a uniform acceleration has a velocity of 10 cm. per second, and 10 seconds afterwards has a velocity of 20 cm. per second. What is the measure of the acceleration?

CHAPTER IV.

WORK, ENERGY AND FORCE.

I.—Work and Energy.

1. The Nature of Work and Energy.

Experiment 1.

Take the plank used in Experiment 1, page 43, and two glass spheres an inch or more in diameter. Elevate one end of the plank so that if one of the spheres is very gently started to roll down the plank it will not stop, but do not elevate it enough to cause it to start from rest. Call the spheres A and B.

Start A down the plank and send B after it at a greater velocity. Observe what takes place when B overtakes A.

1. How is B's velocity changed?

2. How is A's velocity changed?

We have already learned (Art. 5, page 33) that the condition of rest or motion of a body or system of bodies cannot be altered except through some influence outside of itself. The above experiment illustrates in a typical way how the motion of a body may be altered. If the motion of one portion of matter is accelerated it is believed that, as in this case, the velocity of some other portion must in consequence be decreased. The body which produces the motion in the other is said "to do work" on it, while the body whose motion is accelerated is said to have work done on it. When work has been done on a body, it, in turn, acquires an increased power of doing work.

This capacity of a body to do work is called energy.

Energy must be regarded as an entity, something associated with matter in virtue of which it can do work on other portions of matter.[1] The relation between energy and work will be better understood by a study of the following diagrams illustrative of Experiment 1.

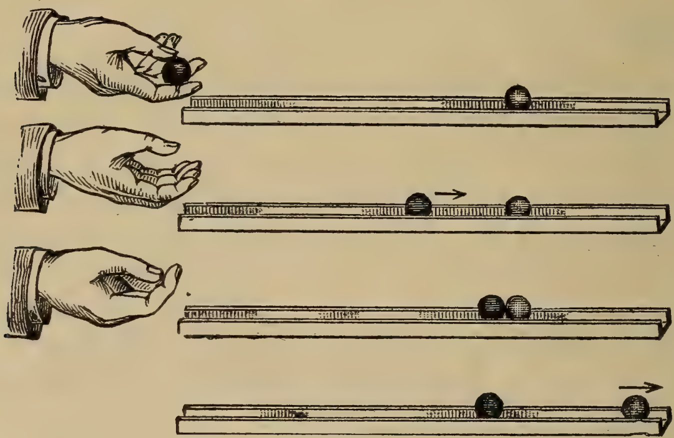


FIG. 35.

In the first, energy is going out of the hand into the first glass sphere.

In the second, energy is stored in the sphere in motion.

In the third, energy is going from the moving sphere into the one at rest.

In the fourth, the energy lost by the first sphere is stored in the second.

[1] "All that we know about matter relates to the series of phenomena in which energy is transferred from one portion of matter to another till in some part of the series our bodies are affected, and we become conscious of a sensation. We are acquainted with matter only as that which may have energy communicated to it from other matter. Energy, on the other hand, we know only as that which in all natural phenomena is continually passing from one portion of matter to another. It cannot exist except in connection with matter."—*Maxwell's Matter and Motion, p. 163.*

Work is done by the hand upon the first sphere and it, in turn, does work upon the second sphere when it comes in contact with it. In other words, **work is done whenever energy is transferred from one body to another.**

Trace the most apparent transferences of energy in the following:—

1. A base-ball is thrown by a pitcher and driven by the batter out into the field, where it is stopped by striking a vane of a windmill, which it sets in motion.

2. A ball shot from a cannon continues to move through the air until stopped by a sand-hill in which it becomes embedded.

In the examples given above, work consists in the acceleration of the motion of some body, but often work is clearly done where this acceleration is not so evident.

Experiment 2.

Place a lump of lead on an anvil and strike it with a hammer. Feel the surface of the lead immediately after it has been struck by the hammer.

1. Was there an acceleration in the mass of the lead as a whole?

2. How was the temperature of the lead affected by striking it?

Experiment 3.

Attach a string to a rough heavy body, and drag it over the surface of another rough body at a uniform rate.

Is there any transference of energy while the body is being moved at a uniform rate?

It is evident that in each of the above cases work is done although there is no acceleration of the bodies as wholes, but we have reasons (to be spoken of hereafter)

for thinking that the molecules of the bodies brought into contact have their motions accelerated.

But there are cases more difficult than these to explain where we have no ground for believing that the motions of even the molecules are accelerated.

If a body, say a pound weight, is lifted at a **uniform speed** vertically, work is certainly done, yet there is no **acceleration** of the body as a whole, nor have we reason to suppose that its particles are made to vibrate more rapidly. Here it is supposed that the work done on the pound weight is not stored up in the pound weight itself, but involves the acceleration of the motion of some material system not evident to our senses which is in some way influenced by the lifting of the weight.

A clock spring furnishes another example. Work is done during the process of winding it up, and the energy which is apparently transmitted to it is available for work whenever it is allowed to uncoil itself. Here, as in the case of the lifted weight, it is impossible for us to specify exactly the systems of bodies set in motion. The weight when raised and the spring when wound up, although at rest, are ready to acquire energy whenever left free to move. Since, however, the source whence they receive it is not apparent, it is customary to speak of them as if possessing the energy which they have the power of acquiring. What is apparent in such cases is that either the position of the body has been changed relatively to some other, as for example when a weight is lifted from the earth or a piece of iron is separated from a magnet; or there has been a change in the relative

positions of the parts of the same body, as in the case of the clock spring when wound up or of a bow when bent.

The energy which a body is thus said to possess in virtue of its position relative to some other body, or the relative position of its parts, is called **potential** energy, while actual energy, or the energy possessed by a body in virtue of its motion, is called **kinetic** energy.

2. Upon what does the Kinetic Energy of a Body Depend?

Experiment 4.

Repeat Experiment 1, substituting in place of B a sphere C having a greater mass.

Cause C to increase the speed of A by the same amount as in the first experiment, and carefully observe the change of velocity of C.

1. In which case is the velocity of the sphere doing the work reduced the more?

2. Is the same work done on A in both cases?

3. How does the energy of A, before work is done on it, compare with its energy afterwards?

4. If the sphere doing the work has the same initial velocity in both cases, in which case has it the greater capacity for doing work?

Such experiments as the foregoing, and our ordinary observations, indicate that **a body possesses energy in virtue of its mass and its velocity.**

The exact relation is as follows:

The energy possessed by a body in motion is directly proportional to the mass when its velocity is constant, and directly proportional to the square of the velocity when the mass is constant.

QUESTIONS.

1. If a piece of tissue-paper is stretched over the mouth of an empty jar and a bullet is carefully placed on the paper it will support it, but if the bullet is allowed to drop from a height on the paper it will pierce it. Explain.

2. A weight may be supported by a fine thread, but if the weight is lifted a short distance and dropped the thread is broken. Explain.

3. Why is a bullet of lead more destructive than one of cork would be?

4. If one railway train runs into another from the rear when both are moving at nearly the same velocity, why is the damage much less than if the front train had been at rest?

5. Under what conditions would the damage be even greater than in the second of the above cases? Why?

6. At what points in the swing of a pendulum does the bob possess (*a*) kinetic energy, (*b*) potential energy?

II.—Force.

3. Nature of Force.

In connection with the transference of energy there arises a quantity of great importance which we shall next investigate.

We have seen in the experiments on the balls A and B (page 48), that when B does work on A the velocity of A is increased, while that of B is decreased, the increase of energy in A and the decrease of energy in B taking place during the brief interval of contact between the two bodies. While the balls are in contact we have an **action** of B on A, and a **re-action** of A on B. This action and re-action constitute what is called a **stress,** and each

aspect of the stress considered by itself is called a **force.** In this case the force to which A is subject is a tendency to acceleration, while that to which B is subject is a tendency to retardation, that is, a tendency to negative acceleration. Hence either force is a **tendency to acceleration.**

Force is usually defined as **anything which tends to produce or to modify motion.**

This definition implies that a tendency to acceleration in a body is due to causes outside of itself, and while it may be accepted, yet it should be remembered that force is not an entity apart from energy, but that whenever a force exists it is, as in the above case, dependent on the energy of some body or system of bodies.

To get a clearer insight into this relation let us consider **some of the manifestations of force.**

In the following experiments particular attention is called to the fact that **at least two bodies are concerned in every force.** This fact is universal.

4. Force as Push or Pull.

The most apparent form in which force manifests itself is in the tendency to acceleration in a body pushed or pulled by another body directly connected with it. In fact, most of our conceptions of force, as well as the terminology applied to it, are derived from the muscular action of animate bodies in pushing or pulling bodies against resistance. Whenever similar results are produced by inanimate agencies, as when a train is pulled or pushed by a locomotive, it has been customary to speak of these agencies as exerting force; but the greatest

care should be observed in transferring to the objective physical world ideas derived from our sensations. We must bear in mind that force is not an objective reality, like matter and energy, but only a condition of matter which is produced by the action of energy. In such cases as the above, the energy which gives rise to the force can usually be traced. When the energy is of the mysterious forms, noted in Art. 1, page 50, its nature is even difficult to imagine; but to imagine "action at a distance" as in the case of action of the so-called attractive forces, is still more difficult, and to some minds, at least, is quite impossible.

5. Attraction of Gravity—weight.

Experiment 1.

Hold any object in your hand a few feet above the table and let go your hold.

1. What evidence have you that this object is subject to a **force**?

2. Did this force exist before you let go your hold?

3. What evidence of its existence had you?

4. If, while you were holding the body, this force had instantly ceased to exist, what would have happened?

Experiment 2.

Support at arm's length a mass of three or four pounds fastened to the end of a string, and while it and your arm are at rest let some one cut the string.

1. What happens to the mass? What happens to your hand and arm?

2. These results prove the existence of what **forces**?

3. Did these forces exist before the string was cut?

4. Were these forces changed by cutting the string?

5. What change, so far as forces are concerned, was produced by cutting the string?

From these observations it is seen that **a force may exist although no apparent acceleration occurs,** provided another force exists to counterbalance the first.

The tendency of a body to acceleration towards the earth is called the **weight** of the body.

6. Law of Gravitation.

The tendency of bodies to move towards the earth is but a particular example of a more universal law of nature. All the evidence goes to show that each portion of matter in the universe influences the motion of every other portion. This is generally known as the **principle of universal gravitation.**

Sir Isaac Newton, from experiments and from observations of the motion of the moon, etc., arrived at the following conclusion:

Between any two bodies in the universe there is a mutual attraction jointly proportional to the masses of the bodies, and inversely proportional to the square on the distance between their centres of mass. For example, if the mutual attraction between two unit masses at a distance of one foot is taken as the unit, the attraction between three units of mass and two units of mass is—

2×3 at a distance of 1 foot

$\frac{2 \times 3}{2^2}$ " " " 2 feet

$\frac{2 \times 3}{3^2}$, etc. " " " 3 feet, etc.

7. Variations in the Weight of a Given Mass.

Apply Newton's Law of Gravitation to answer the following questions:

1. How will the weight of a body vary (*a*) when it is being carried up in a balloon? (*b*) when it is being taken below the surface of the earth into a mine?

2. What would be the weight of a given mass if it were placed at the centre of the earth?

3. If the mass of the earth is 80 times, and its diameter is four times that of the moon, how does the weight of any mass at the surface of the earth compare with the weight of the same mass at the surface of the moon?

4. At what distance from the earth's surface is the weight of any mass one-fourth of its weight at the surface?

5. At which region will the weight of the same mass be the greater, at the Equator or at the Poles? Why?

8. Electric Attraction and Repulsion.

Experiment 3.

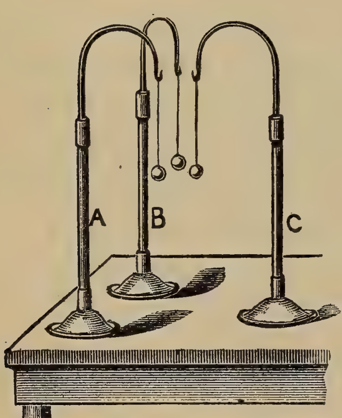


FIG. 36.

Suspend three pith balls from convenient supports, as shown in Fig. 36, using fine silk thread. Arrange the apparatus so that you may vary the distance between the balls. Call the balls A, B and C.

1. Touch the balls with your hand. Do you observe any tendency on the part of the balls to come together or to separate?

2. Rub a piece of vulcanite briskly on a piece of silk or on your coat sleeve, and having moved B and C away, touch A with it,

allowing the ball to roll over the rubbed surface so that all parts of its surface may come in contact with it. Now move B toward A, not allowing them to touch.

What do you observe?

Do you find **one** or **both** balls subject to a force?

3. Move B and C toward each other. Have you evidence of any unusual force?

4. Move C toward A, and what is the result?

5. Roll A in the fingers for a moment and again bring it near B and C.

What is the result?

In the above experiment A has been **electrified** by bringing it in contact with the rubbed vulcanite. We expended muscular energy in electrifying the vulcanite, and hence some other form of energy must have resulted. The precise nature of this energy is not known, but we see that it can produce force.

Experiment 4.

Electrify both A and B and bring them near each other.

1. What is the result in this case?

2. Bring each separately near C, and what is the result?

3. How many bodies are concerned in any force of whose existence you have evidence?

4. Can you electrify C from A or B? Try.

5. What is the result when an electrified ball is rolled in the fingers?

9. Magnetic Attraction and Repulsion.

Experiment 5.

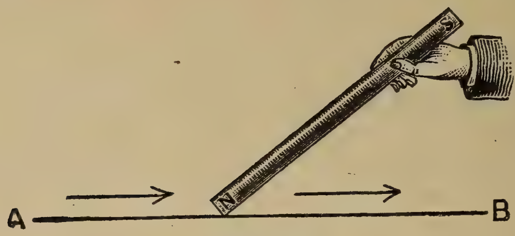


FIG. 37.

Magnetize three sewing needles by rubbing them in one direction with a strong magnet (Fig. 37). Suspend two of them by silk fibres, as shown in Fig. 38.

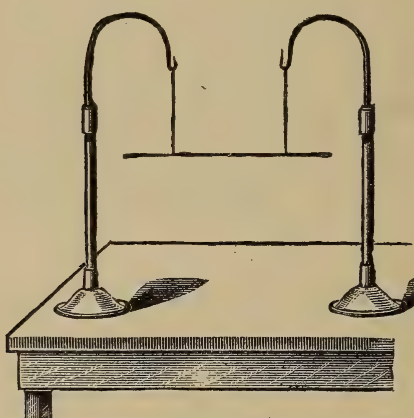


FIG. 38.

1. What position does each assume when left to itself at a considerable distance from the other? What is the result if it is disturbed?

2. What evidence have you that the needle is subject to one or more forces?

A magnetized needle suspended so that it is horizontal and is free to rotate about its point of support in a horizontal plane is called a **compass needle.** The end having

a tendency to point toward the north is called the **north-seeking pole,** and the other end is called the **south-seeking pole.**

Experiment 6.

Take the remaining magnetized needle in your hand and hold, first one end and then the other, near the north-seeking pole of one of the suspended needles.

1. What results do you observe ?

2. Of what forces have you evidence ?

Repeat the experiment, holding each pole to the south-seeking pole of the suspended needle.

Experiment 7.

Place the two suspended needles so that the north-seeking pole of one shall be near the south-seeking pole of the other.

1. Do you find one or both needles subject to force ?

2. What attractions or repulsions are observed when (*a*) like poles are brought near each other, (*b*) unlike poles ?

Experiment 8.

Stretch, in a direction north and south, a wire through

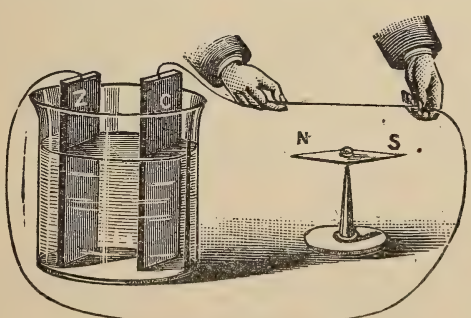


FIG. 39.

which an electric current is flowing, first above and then below a compass needle (Fig. 39).

An electric current may be obtained by placing a copper and a zinc plate in a vessel containing dilute sulphuric acid in the proportion of about ten parts of water to one of acid, and connecting them by a wire as shown in figure.

1. What is the result ?

2. Are the poles of the magnet subject to forces ? If so, in what direction do the forces act ?

10. Molecular Attraction.

Experiment 9.

Sprinkle a few drops of water on a pane of glass and hold the pane in a horizontal plane with the wet side underneath.

1. What force do you know each drop of water is subject to ?

2. Since the drop does not fall, of what other force have you evidence ?

3. What inference regarding mutual attraction between particles of water must you draw from the fact that the drops of water remain entire ?

4. Is mutual attraction confined to bodies of sensible (such as may be perceived by the senses) magnitude ?

Experiment 10.

Heat two pieces of glass to redness and press the heated parts together. Allow them to cool and try to separate.

1. Of what force does the result furnish evidence ?

2. Give other examples of similar phenomena.

Experiment 11.

Fold a sheet of tea-lead many times and subject it to very great pressure either in a vise or by hammering.

1. On examining the resulting lump, what evidence have you of the existence of mutual attraction between the particles of the lead ?

2. Why are you able to make a mark on the blackboard with a piece of chalk?

3. To what is the efficiency of glue due.

From such experiments as the above we see that **there is mutual attraction between the molecules of bodies, which becomes very great when the particles are brought sufficiently close to one another.** This attraction is called **cohesion** or **adhesion,** according as the molecules are of the **same** or of **different substances.**

CHAPTER V.

MEASUREMENT OF MASS.

1. How may Equal Masses be Determined and Mass Measured?

We cannot compare masses as we do lengths by placing them side by side, because we are not able to judge with the eye when two bodies contain exactly an equal amount of matter. An indirect method must be used. The law of gravitation furnishes the most convenient means. According to this law the weights of equal masses at the same place are equal.

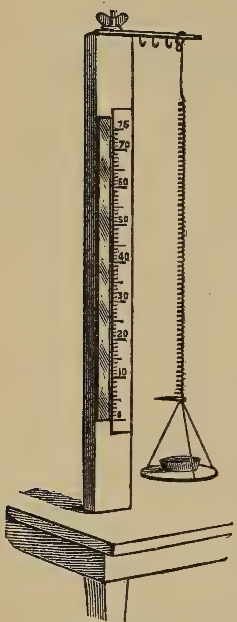


FIG. 40.

Our next step, then, is to determine some practical methods of applying this fact to the solution of this problem.

Experiment 1.

To construct a Jolly Balance and use it in determining equal masses.

Attach to one side of a vertical support[1] a scale graduated in millimetres, and alongside of it fasten a strip of mirror glass, as shown in Fig. 40. Suspend from a horizontal arm attached to the support a scale-pan by means of a coil-spring made by winding some fine steel piano wire around a mandrel. A small pointer or bright bead is fastened to the spring at its lower end. Care should be taken in adjusting the spring to the scale to

[1] Supports of the kind illustrated are convenient for other purposes and may be either permanently mounted on movable bases, or, as in figure, made to screw into nuts fixed in the laboratory tables. The horizontal arm is attached by screwing a threaded bolt into a hole in the top of the support and clamping it with a thumbscrew.

see that when the pointer is pulled down to the bottom of the scale it will return to its original position when the stretching force is removed.

Place sufficient shot in the scale-pan to lower the pointer a few divisions on the scale and determine accurately the exact position of the pointer by so placing the eyes that the pointer and its image in the mirror shall be in line.

Remove the shot and pour sand into the scale-pan until the pointer again stands at the same position on the scale.

1. What is the cause of the extension of the spring?

2. Of what is the amount of the extension in each case, therefore, a measure?

3. How does the mass of the shot compare with the mass of the sand?

Experiment 2.

Place the shot used in the last experiment in one scale-pan of an equal-arm balance and the sand in the other. What is the result?

The above experiments illustrate two of the most simple methods of estimating equal masses. **Thus if we find that two masses stretch, to the same extent, the same elastic body, or counterpoise each other at the end of an equal-arm balance, we infer that these masses are equal.**

The apparatus shown in Fig. 40 is usually called a Jolly's balance. Various modifications of it are in use for estimating mass. Fig. 41 shows one of the most common forms. The figures on the scale indicate the number of units of mass suspended on the spring to bring the pointer to the lines opposite them.

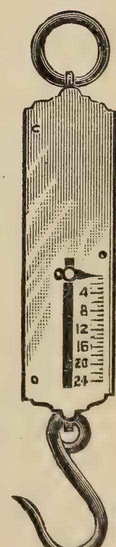


FIG. 41.

2. Description of the Balance.

But the method of equal-arm balance is the one most commonly used for the determination of equal masses. Fig. 42 shows a common form of the balance,[1] which consists of a metal beam A B, supported at the centre on the knife-edge C, usually a three-cornered steel bar passing horizontally through the beam at right angles to it. The sharp lower edge of C rests on a smooth horizontal plate of steel or agate fixed on a pillar, P. Scale-pans are hung by means of steel or agate plates on

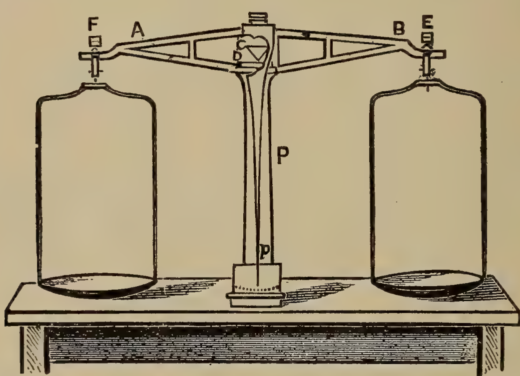


FIG. 42.

knife-edges placed at E and F near the ends of the beam and at equal distances from its centre. A pointer, *p*, which moves over a graduated scale, is attached to the centre of the beam, as shown in the figure. When unloaded, or when the pans are equally weighted, the balance should rest in equilibrium, with the beam horizontal, and the pointer at zero on the graduated scale. Every good balance should have also some device for supporting the pans.

[1] For manual training exercise, see Appendix, page 325.

3. Units of Mass.

The English unit of mass is a certain quantity called a pound, the standard for which is the quantity of matter contained in a block of platinum kept in the office of the standards in London.

The metric unit of mass is the gramme, generally now written in English, gram. It is equal to the mass of one cubic centimetre of water at four degrees centigrade. The French standard is a block of platinum which contains 1,000 grams, or one kilogram, preserved in the French archives.

4. Multiples and Fractions of the Metric Unit.

A mass of	$\frac{1}{10}$ or ·1	of a **gram** (gm.)	is called a	**decigram** (dgm.)
"	$\frac{1}{100}$ or ·01	"	"	**centigram** (cgm.)
"	$\frac{1}{1000}$ or ·001	"	"	**milligram** (mgm.)
"	10	**grams**	"	**decagram** (Dgm.)
"	100	"	"	**hectogram** (Hgm.)
"	1000	"	"	**kilogram** (Kgm.)

5. English Equivalents.

1 gram	=	15·4323	grains
	=	·0022046	avoirdupois pound
1 kilogram	=	2·2046213	avoirdupois pound
1 grain	=	·064798950	grams
1 ounce avoirdupois	=	28·349541	grams
1 pound "	=	·45359265	kilogram

6. Approximate Values

1 gram	=	15·4	grains
1 kilogram	=	$2\frac{1}{5}$	pounds
1 milligram	=	·0154	grain
1 grain	=	64·8	milligrams
1 ounce	=	$28\frac{1}{3}$	grams
1 pound	=	454	grams

1. How many milligrams in 20·34 gm., 30·42 cgm., ·325 Kgm.?

2. How many kilograms in 856·3 mgm., 345·8 cgm., 934·2 gm.?

3. How many centigrams in 32·9 Kgm., 92·3 gm., 83·12 mgm.?

4. If 324 is the measure of a mass when the unit of mass is the gram, what will be its measure when the unit is (*a*) the kilogram, (*b*) the milligram?

5. Is the unit of mass a fundamental or a derived unit?

7. Units of Mass and Units of Force Distinguished.

On account of the relation noted above between mass and weight, it has been found convenient to estimate the magnitudes of forces by observing the masses which they will support against gravity at the earth's surface.

In this case **we take as our unit force, the force that will support the unit mass,** *e.g.*, the pound or the gram. Thus a pound force means the force that will support the pound mass at the surface of the earth, etc.

It will be seen that we use the word "pound" in a double sense. We use it as the name of a particular mass, and also as the name of the force required to support that mass at the surface of the earth. Whenever there is any chance of being misunderstood, it is well to use the phrase **pound mass** or **pound force,** according to which is intended. The same may be said of the words "gram," "kilogram," etc.

8. Weights.

For convenience and accuracy in estimating mass, sets of "weights" are used. These are pieces of metal adjusted to contain multiples and fractions of the quantity of matter contained in the selected unit.

Metric weights are usually arranged in a box in the following order (Fig. 43):—

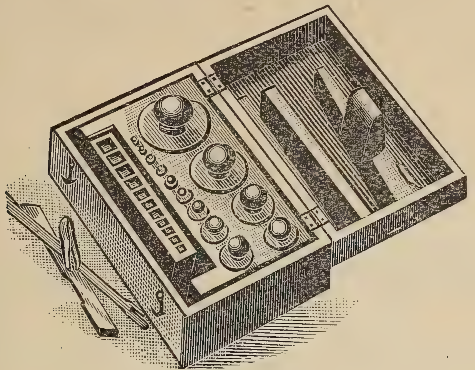


FIG. 43.

	Brass Weights.		*Platinum or Aluminium Weights.*	
1000 gm.	50 gm.	5 gm.	5 dgm.	5 cgm.
500	20	2	2	2
200	10	2	2	1
100	10	1	1	1
100				

FIG. 44.

The milligram weights are seldom used. In delicate balances where it is necessary to weigh to a milligram, a piece of platinum, generally weighing one centigram (Fig. 44), called a rider, is placed on the beam at graduated distances from the centre (Fig. 45). By this means fractions of a milligram may be estimated.

9. Rules for the Use of the Balance.

1. Keep the balance dry and free from dust.

2. See that the balance is properly adjusted, so that it will, when unloaded, either rest in equilibrium with the pointer at the zero mark on the scale, or will swing equally on either side of zero.

3. Place the body whose mass is to be ascertained in one scale-pan, and after the largest weight that can be used is placed in the other, try the others in order. Miss none.

4. To determine the equilibrium do not wait until the balance comes to rest. When it swings equally on either side of zero, the mass in one pan equals that in the other.

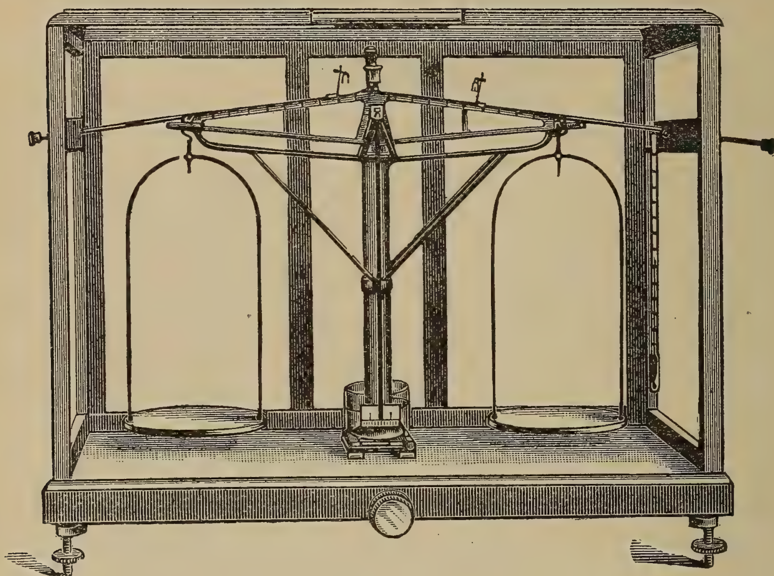


FIG. 45.

5. Place the largest weight in the centre of the pan, and the others in the order of their denominations.

6. Keep the pans supported when weights are to be added or taken off.

7. Small weights should not be handled with the fingers. Use forceps.

8. Weigh in appropriate vessels substances liable to injure the pans. For counterpoise use shot and paper.

9. Never use the balance in a current of air.

10. Experiments in Estimating Mass.

1. Determine by means of a balance and weights the masses of several small pieces of rock or metal.

2. By weighing find the metric equivalent of an ounce weight.

3. Measure off 50 cm. of iron stove-pipe wire, weigh it and calculate the weight in grams per centimetre in length.

4. Take another piece of the same wire, of unknown length, weigh it, and from the weight per centimetre determined in the last experiment, calculate the length of the wire. Verify your result by measuring its length with a metre scale.

What is your percentage of error?

5. Use the weights provided in your laboratory to construct from pieces of brass or aluminium wire a set of centigram weights, consisting of weights of one, two, three, four and five centigrams. Bend the wires into the shapes shown in Fig. 46 to indicate their masses.

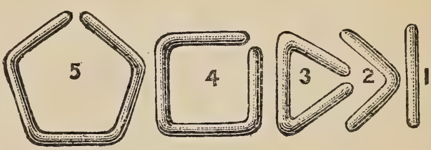


FIG. 46.

6. Cut sheet brass into strips with a pair of shears, and cut from these strips a set of decigram weights.

7. Counterpoise a beaker on a balance, run into it from a burette 100 c.cm. of water. Weigh the water.

What is the mass of the water?

What is the mass of one cubic centimetre of it?

8. Weigh one cubic centimetre of water by running it from a burette into a counterpoised watch glass.

1. How does your result compare with that obtained in Experiment 7?
2. What would one litre of the same water weigh?

9. Find the internal volume of a flask up to a certain mark by weighing the water it contains.

10. Counterpoise a beaker on a balance, and then weigh a given body by placing it in the other scale-pan and determining the volume of water, delivered from a burette into the beaker, which will counterpoise it.

11. Meaning of the term Density.

By **density** is meant the **mass of a unit volume of a substance.**

There is a tendency to use the word loosely to refer in a general way to the relative degree of closeness of the molecules of a body, but the number of molecules contained within a unit volume is only one factor in density.

Upon what other factor or factors does the quantity of matter in a unit volume depend?

12. Measure of Density.

The density of a body is measured by the number of times it contains some definite density assumed as a unit. The unit density is the density of a body a unit volume of which contains a unit mass. For example, if the unit volume is the cubic centimetre and the unit mass the gram, the unit density is one gram per cubic centimetre. A density, therefore, whose measure is, say six, is the density of a body which contains six grams of mass in each cubic centimetre of volume.

13. Computation of Density from Measurements of Mass and Volume.

1. The mass of a cubical block of metal each side of which is 4 cm., is 352 grams. What is the density of the metal in grams per cubic centimetre?

2. What is the density in grams per cubic centimetre of copper, if a piece of copper wire 3·5 mm. in diameter and 16 cm. long, has a mass of 13·86 grams. ?

3. The dimensions of a pound rectangular bar of soap are $9'' \times 2\frac{1}{2}'' \times 1\frac{1}{4}''$. What is its average density in ounces per cubic inch ?

4. A rectangular box 5 ft. long, 4 ft. wide, and 2 ft. deep, contains when filled 2,500 pounds of water. What is the density of water in pounds per cubic foot ?

5. Compute the densities of samples of different liquids such as alcohol, milk, mercury, etc., after having determined the mass of each by weighing, and the volume by measurement with a burette. How many times does the density of each contain the density of water ?

6. Measure the diameter of a copper wire with a micrometer caliper and its length with a scale, and from the result compute the density of copper in grams per cubic centimetre. How many times does the density of the copper contain the density of water ?

7. Compute the densities of several kinds of rocks or minerals by determining the volumes of small pieces by the displacement of water (see Exp. 6, page 27) and the masses by weighing. How many times does the density of each contain the density of water ?

Experiment 3.—To determine the relation of the volume to the mass of different masses of the same substance, and to represent the results graphically.

Select several steel bicycle balls of different sizes, weigh each, measure its diameter, and compute its volume.

Take a sheet of cross-section paper and choose a horizontal line OX at or near the bottom of the sheet to be called the axis of abscissæ and a vertical line OY at the left hand margin to be called the axis of ordinates, call the point O at which these lines intersect the origin.

Selecting convenient units of length to represent units of mass and volume, lay off on OX, distances Oa, Ob, Oc, etc., to

represent the masses computed, and Oa_1, Ob_1, Oc_1, etc., on OY to represent the corresponding volumes. Mark the points where the vertical lines through *a*, *b*, *c*, etc., and the horizontal ones through a_1, b_1, c_1, etc., cut, and through these points of intersection trace a smooth curve, that is, one which passes through or near most of these points.

Such curves are exceedingly useful in representing the relations between successive values of related quantities. They assist us by their appeal to our visualizing tendency to strengthen our conceptions of these relations, and enable us to detect and interpret many relations which otherwise would pass unnoticed. They also frequently enable us to determine by inspection values, not measured of one of the varying quantities from the corresponding values of the other. For example, if we have plotted the curve representing the relation between the volume and the mass of different masses of the same kind of steel as required above, we can estimate by means of it the masses of other balls of the same steel, whose volumes are known, by simply observing the distances on the axis OX which correspond to the distances on OY.

CHAPTER VI.

PROPERTIES AND LAWS OF SOLIDS.

I.—Hardness.

1. What is Meant by the Term Hardness as Applied to Solids?

Experiment 1.

Rub together, with the object of determining which will scratch the other, (*a*) a cake of paraffine and a piece of sheet lead, (*b*) a piece of sheet lead and a piece of sheet copper, (*c*) a piece of sheet copper and a steel knife blade.

Substances not easily abraded, that is, whose particles are not easily rubbed away, are said to be **hard,** and the **resistance which a body offers to being abraded by another is called hardness.**

The above experiment indicates that hardness is a relative property. A body which is hard when compared with one body may be soft when compared with another. The relative hardness of two bodies is ascertained by determining which will scratch the other.

Experiment 2.

Obtain specimens of as many as possible of the following minerals and test their relative hardness, making a list of them arranged in the order of hardness: Topaz, Calcite, Corundum, Feldspar, Diamond, Talc, Fluorspar, Gypsum, Quartz, Apatite.

Hardness is an important property as a basis of classification in the science of mineralogy.

2. What is the Effect of Heating and Cooling on the Hardness of the Metals, Steel and Copper?

Experiment 3.

Take two pieces of steel piano wire, make each red-hot, allow one to cool slowly, but cool the other quickly by dipping it into cold water. Scratch each with a file.

Which is the harder?

Experiment 4.

Repeat Experiment 3, using copper instead of iron wire.

Which is the harder, the wire cooled quickly or the one which is allowed to cool slowly?

3. Tempering—Annealing.

Changing the hardness of a metal by heating it and cooling it in different ways is called **tempering.**

The process of making a hard and brittle metal softer and more flexible is called **annealing.**

How is iron annealed? How is copper?

4. Is a Dense Body Necessarily Hard or Necessarily Soft?

To answer this question consider:—

1. Which is the denser metal, iron or gold? Which is the harder?

2. Which is the denser metal, lead or platinum? Which is the harder?

5. Does Hardness Necessarily Imply Brittleness, or Tendency to be Broken by a Blow?

To answer this question determine which is the harder and which the more brittle in the following pairs of substances: (*a*) copper and chalk, (*b*) copper and glass, (*c*) glass and steel.

II.—Ductility.

6. What is Meant by the Term Ductility as Applied to Solids?

Experiment 1.

Take a piece of glass tubing or a glass rod, heat it in the flame of a Bunsen burner or spirit lamp until it becomes quite soft, then draw it out (Fig. 47).

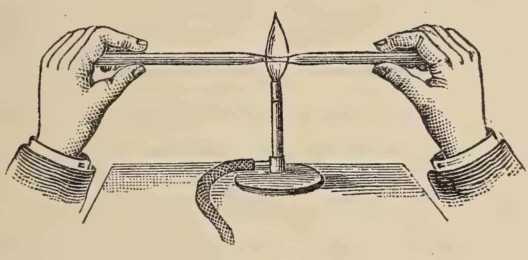


FIG. 47.

The property of being extended in length by being drawn out into wires or threads is called ductility.

Experiment 2.

Compare the ductility of a piece of sealing wax at the ordinary temperature with that of a piece which has been heated for a short time in boiling water.

Many metals are quite ductile even when cold. Of these, platinum is the most ductile. Although this metal is nearly three times as dense as iron, a wire of it has been drawn to such a degree of fineness that a mile's length weighed but one grain.

Gold, silver, copper and iron are also very ductile.

Is there any relation between (*a*) density and ductility, (*b*) hardness and ductility?

Wires are made by drawing the metal through holes in hard metal plates.

III.—Malleability.

7. What is Meant by the Term Malleability as Applied to Solids?

Experiment 1.

Take a small lump of lead and place it on an anvil or iron plate, and strike it several times with a hammer.

How is its shape affected by hammering?

The property of being extended in surface when hammered or rolled is called malleability.

This property is possessed by many metals. Under the hammer the order of malleability of useful metals is, lead first, tin second, and gold third. When the metals are extended by being pressed between rollers, gold is the most malleable, silver stands second, copper third, and tin fourth.

1. Compare specimens of tin foil, lead foil, and gold leaf.

2. How are the relative positions of the molecules of a body affected by its being extended in (*a*) surface, (*b*) length?

3. Why is it that the most ductile metals are malleable?

IV.—Plasticity.

8. What is meant by the term plasticity as applied to solids.

Experiment 1.

Support one end of a stick of sealing wax (Fig. 48), and

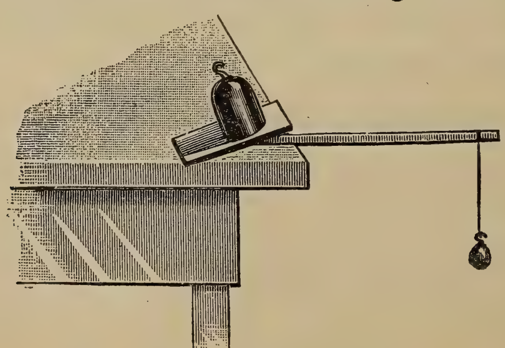


FIG. 48.

hang a weight of about 50 grams from the other end. Allow it to stand for two or three days.

1. What change has taken place in the shape of the sealing wax?

Remove the weight.

2. Does the wax recover its original shape?

The property of changing shape under the action of a continuous force without exhibiting a tendency to regain the original form, is called plasticity.

1. Name some other plastic bodies.

2. Is glass plastic?

To answer this question support a long, straight, glass tube on two pegs placed near its ends, and observe whether it has changed its shape after the lapse of a month or two.

3. Is ice plastic?

Read an account of the action of ice in glaciers.

V.—Tenacity.

9. What is Meant by the Term Tenacity as Applied to Solids?

Experiment 1.

Try to break a small wire or thread by attempting to pull its parts asunder.

Does the wire or thread offer resistance to the force applied?

The resistance which a body offers to the separation of its parts is called tenacity.

Experiment 2.

Measure with a micrometer caliper the diameters of several small copper wires and determine the **breaking stress** of each as follows :—

Fasten one end of the wire to a peg and the other to a spring balance, and gradually pull on the balance until the wire breaks (Fig. 49).

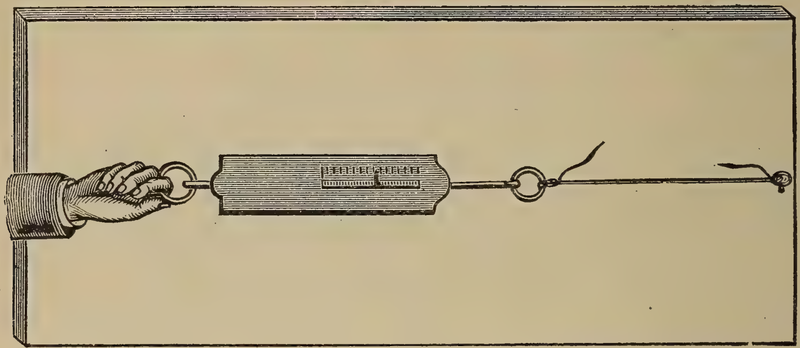


FIG. 49.

From the measures of the diameters compute the areas of the cross sections and plot a curve showing the relation of the area of the cross section to the breaking stress of the wires.

Repeated experiments of this kind have shown that the tenacity, or tensile strength, as it is sometimes called, of a wire or bar is proportional to the area of its cross section and is independent of its length.

Of metals, iron has the highest tensile strength. A bar of steel whose cross section is one square inch will sustain 134,256 pounds.

1. What other properties of bodies are dependent upon tenacity?

2. Wire ropes are usually stronger than bars of the same metal of equal mass and length. How does drawing a metal into a wire affect its tenacity?

VI.—Elasticity.

10. What is Meant by the Term Elasticity as Applied to Solids?

Experiment 1.

Try to stretch a piece of rubber band or tubing. Press a rubber eraser against a hard substance. Try to bend

it. Squeeze in the hand a hollow rubber ball containing air.

1. What changes take place in the volume or the shape of the band, of the eraser, and of the ball, when force is applied to each?

2. What happens when the force is reduced or ceases to act?

The property of a body in virtue of which, after its size or shape has been altered by the action of force, it reacts against the force and returns to its original size or shape, more or less completely, on the removal of the force, is called elasticity. That is, the elasticity is the internal stress which is called out in a body when it is subject to a strain.

When the strain is one of change of volume (compression or dilation) the stress produced is called **elasticity of volume**; when the strain is one of change of shape (distortion) the stress which is called out by it is called **elasticity of form.**

1. Which of the bodies used in Experiment 1 possess elasticity of volume? Which elasticity of form?

2. What elasticities are possessed by solids? by liquids? by gases?

11. Limit of Elasticity.

Experiment 2.

Arrange apparatus as for construction of Jolly Balance (Art. 1, page 62), using for the spring fine piano wire and making the coil about 2 cm. in diameter.

Place a series of weights in the scale-pan, beginning with a small one, and replacing each with a heavier one. Note after the removal of each weight whether the pointer returns to its original position on the scale.

1. Is there a limit beyond which, if the coil is stretched, it does not resume its original length?

2. If so, what weight was required to stretch it to this point?

Experiment 3.

Fasten one end of a piece of copper wire A in a clamp or vise, as shown in Fig. 50. Place a pointer B opposite the other end.

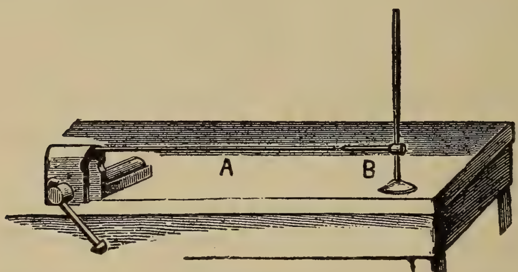


FIG. 50.

Bend the wire a little by pulling the free end aside a short distance. Let go.

Does the wire take its original position when it ceases vibrating?

Repeat the experiment, bending the wire a little more each time.

Is there a limit beyond which, if it is bent, it will not take its original position when the disturbing force is removed?

The property of a body in virtue of which it may be bent is called flexibility.

1. How does elasticity differ from flexibility? Give illustrations.

2. What change takes place in the arrangement of the molecules on (*a*) the convex, (*b*) the concave side of a body, when it is bent?

Experiment 4.

Fasten one end of a copper wire, about No. 10 and 50 cm. long, to a support, and to the other end attach a heavy

weight to which is fastened a pointer (Fig. 51). Note the position of the pointer on a circular scale drawn on paper. Twist the weight around a **little way.**

Does it return, after it ceases vibrating, to its original position?

Repeat the experiment, turning the weight more each time.

Is there a limit beyond which, if the weight is turned, the pointer does not return to its original position?

A body is said to be perfectly elastic when it recovers completely its volume or shape after strain. Many solids are perfectly elastic if not strained beyond a certain limit, called the **limit of elasticity.** When strained beyond this, they do not completely recover their original volume or shape, but take a permanent "set."

FIG. 51.

1. If a heavy load strains a bridge beyond its limit of elasticity, what effect is produced on the shape of the bridge? What effect would the same load produce if it passed over again?

2. Why do the springs of carriages often become "sagged?"

3. Why has the use of the common form of "spring balance" for commercial purposes been made illegal in Canada?

4. Name some bodies (*a*) in which the limit of elasticity is soon reached, (*b*) in which the limit of elasticity is near the breaking point, (*c*) which have a high limit of elasticity.

5. Are there any bodies belonging to (*a*) and (*b*)? to (*a*) and (*c*)? to (*b*) and (*c*)? If so, give examples.

12. Has the Length of Time during which a Force acts any Effect on the Limit of Elasticity of a Body?

Experiment 5.

To answer this question, take a wooden bar A, support it as shown in Fig. 52, and place on it a weight which does not apparently strain it beyond its limit of elasticity. Allow the weight to remain on the bar for a few days.

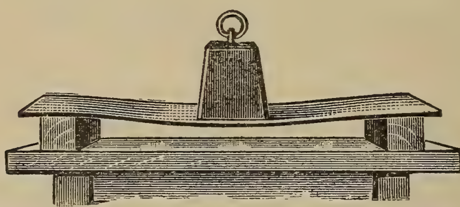


FIG. 52.

1. Is the bar permanently bent?
2. Why do archers keep their bows unbent when not in use?
3. Have gases a limit of elasticity? have liquids?

13. Measure of Elasticity.

The elasticity of a body is measured, not by the amount of change in shape or in volume which it will undergo and still regain its original shape or volume, but by the force with which the displaced particles will tend to revert to their original positions. This is the force necessary to produce the change in shape or volume. For example, liquids have greater elasticity than gases, because greater force is necessary to produce a specific change in the volume of a liquid than in the volume of a gas, since the particles of the liquid tend with greater force to return to their original positions.

Generally, the elasticity of solids is greater than that of liquids.

1. To which must the greater force be applied to change its length by one millimetre, a bar of rubber or one of steel of the same size and length?

2. Which has the greater elasticity?

3. Which is the more extensible?

4. Which is the more compressible?

5. Why does a ball rebound when it strikes a hard surface?

To answer this question touch the ball to the surface covered with oil or paint and note the size of the spot made on the ball. Now let the ball drop from a height on the surface and again observe the size of the spot.

1. Compare the spots made in the two cases.

2. What change must have taken place in the ball when it came in contact with the surface?

3. What would this cause?

Experiment 6.

To plot (1) a curve *a* showing the relation between the load carried by a rod and its deflection, the length being unchanged; (2) a curve *b* showing the relation between the deflection and length, the load being unchanged.

Make a rod about two metres long and one centimetre

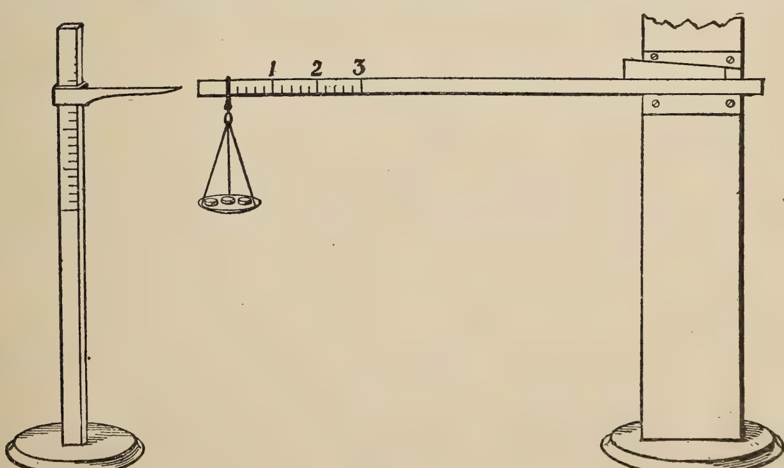


Fig. 53.

square and attach it, by means of a wedge, to an upright support as shown in Fig. 53. Suspend a scale-pan from a

loop of wire or metal sleeve made to slide on the rod. Arrange a vertical scale with sliding pointer.

Place the pointer opposite the end of the rod and note its height. Add a series of weights to the scale-pan, by regular amounts, noting in each case the amount of the deflection of the rod as shown by the amount of change in the position of the pointer. Tabulate results and plot curve *a*.

Vary the experiment by leaving the load constant and changing regularly the length of the rod. Tabulate results and plot curve *b*.

VII.—Structure—Crystalline and Amorphous.

14. What is Meant by the Terms Crystalline and Amorphous as Applied to Solids?

Experiment 1.

Dissolve 100 grams of alum in 500 cubic centimetres of water. Hang several strings in the solution and set aside for a few hours.

1. Are the pieces of alum which have separated from the solution alike in **shape**?

2. Study their forms and make drawings of some of them.

Experiment 2.

Repeat Experiment 1, using (*a*) a solution of copper sulphate, (*b*) a mixture of the solution of alum and the solution of copper sulphate.

Experiment 3.

Clean a strip of glass, slightly warm it, and pour upon it a few drops of a hot solution of ammonium chloride.

1. Describe what takes place.

2. What is the substance left on the glass?

3. Place the glass on the stage of a microscope, look at the substance with a low power objective, and describe its appearance.

Experiment 4.

If you have a porte lumiere or projection lantern, wet a clean glass plate the size of a lantern slide with the hot solution of ammonium chloride, place it in the slide holder and focus it on the screen with a short focus lens.

Observe the beautiful arborescence.

Experiment 5.

Pour a saturated solution of common salt into a saucer. Put it away and keep it free from dust for a few days.

What do you observe on the bottom of the saucer?

Experiment 6.

Obtain pieces of mica, chalk, coal, copper sulphate, glass, Iceland spar, and roll sulphur. Try to cut or split them in different directions.

1. Is each cut or split in every direction with equal ease?

2. Are the surfaces exposed at all separations of the same substance the same in appearance? If not, point out some of the differences.

When the particles of which a body is composed are arranged in a more or less regular form the body is said to be **crystalline** in its structure; but when these particles possess no apparent regularity in their arrangement it is said to be **amorphous.**

1. Which of the bodies named in Experiment 6 above are crystalline and which amorphous?

2. Is ice crystalline? Observe it when it **begins** to form. Place a thin sheet of it before the condenser of a porte lumiere or projection lantern and focus on the screen.

3. Is snow crystalline? Place a few flakes on a dark cloth and observe them through a magnifying glass.

The variety of forms in which the particles of different substances arrange themselves is almost endless. This is the case probably because the attraction of cohesion is not the same all round the molecule, but like the attraction of a magnet, is concentrated at certain points or poles. When the molecules are free to move, these points, on account of their mutual attractions or repulsions, take set positions, and the structure of the body thus becomes regular in form.

This tendency to arrange themselves in regular order is, perhaps, possessed by the molecules of most bodies; and even when, on account of the lack of freedom of the molecules, it does not render itself apparent, it is no doubt often still present. For example, wrought-iron is amorphous, but by constant jarring it becomes crystalline. Here the molecules receive a certain amount of freedom at each jar, and in course of time the constant tendency to regularity of structure becomes apparent.

QUESTIONS.

Give the properties of the following solids which make them useful for the purposes indicated :

1. Lead for (*a*) water pipes, (*b*) bullets.
2. Rubber for (*a*) bicycle tires, (*b*) overshoes.
3. Iron for (*a*) boiler plates, (*b*) chains.
4. Steel for (*a*) pens, (*b*) watch springs, (*c*) swords.
5. Silk for (*a*) clothes, (*b*) thread.
6. Hair for (*a*) mattresses, (*b*) mixing in mortar.
7. Cork for (*a*) bottle stoppers, (*b*) soles for shoes.
8. Leather for (*a*) harness, (*b*) shoes.

CHAPTER VII.

PROPERTIES AND LAWS OF LIQUIDS.

I.—Fluidity—Viscosity.

1. Viscosity.

Experiment 1.

Pour several liquids such as alcohol, water, oil, syrup, honey, tar.

1. Do they all flow with equal freedom?
2. Is the shape of each changed by the action of the smallest possible force?

A **perfect fluid** would offer no resistance to forces tending to change its form, but the perfect fluid is only an ideal conception. Every fluid actually does offer some resistance to change of shape, although in the case of a gas like hydrogen this resistance is extremely small.

This tendency to rigidity in fluids is called **Viscosity.**

Liquids differ widely in fluidity. Some, like ether, are quite mobile; while others, like pitch, are very viscous.

The rigidity of a perfect solid would be infinitely great, and the viscosity of perfect fluid infinitely small.

II.—Cohesion—Adhesion.

Experiment 1.

Place a piece of wood in water, take it out and observe its surface.

1. What do you find on the surface of the wood?
2. What force holds it together?
3. What force holds it to the wood?

Experiment 2.

Repeat Experiment 1, using mercury instead of water.

How do you account for the difference in the result?

Experiment 3.

Fasten to the centre of a glass[1] disc with sealing wax a wire staple of the form shown in Fig. 54, and tie to this a **thin** rubber band, and gently lower the disc until its surface touches the surface of the water. Lift up on the rubber. Examine the lower surface of the disc when it has separated from the water.

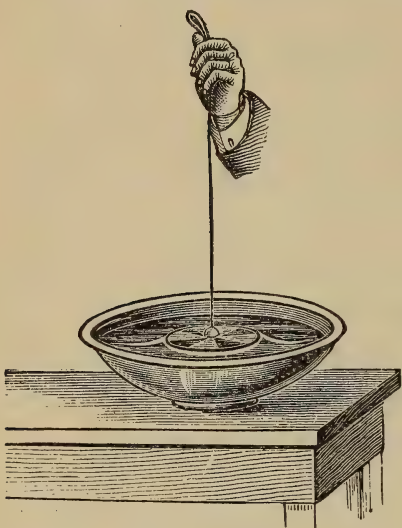


FIG. 54.

1. What evidence have you that you had to exert force to separate the disc from the water?

2. In separating the disc from the water, what force was overcome, the cohesion among the particles of the disc, the adhesion between the disc and the water, or the cohesion among the particles of the water? Give your reasons.

Experiment 4.

Repeat Experiment 3 after having greased the lower surface of the disc.

Was force necessary to separate the disc from the water? If so, what force had to be overcome to cause the separation?

Experiment 5.

Repeat Experiment 3, using mercury instead of water.

1. Is there any adhesion between the disc and the mercury?

[1] In this and the following experiments in this chapter great care should be taken that the glass used is CLEAN. It is best cleansed by washing first in a solution of caustic soda, and then in water.

2. Is there any cohesion among the particles of the mercury ?

3. In pouring liquids from vessels a glass rod is often placed as shown in Fig. 55. Why does this prevent the liquid from running

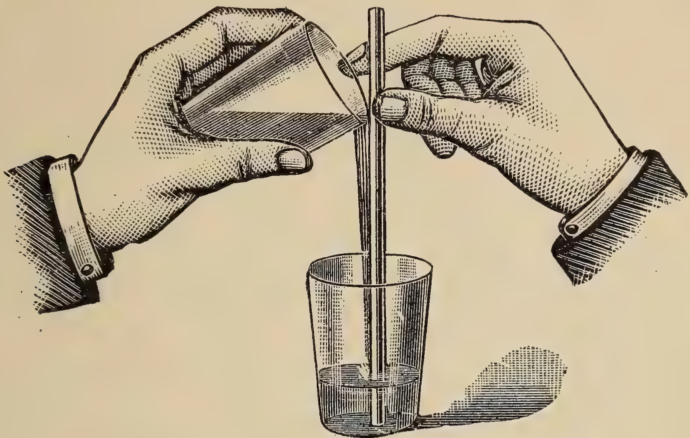


FIG. 55.

down the side of the vessel ? Would it be of any use in pouring mercury from a glass vessel ? Give reasons for your answers.

III.—Surface Viscosity, Surface Tension and Capillarity.

2. Surface Viscosity.

Experiment 1.

Place a clean, dry sewing needle on the surface of water by lowering it so that both ends will touch the surface at once. To do this use a fine wire bent in the form shown in Fig. 56. Keep trying until you succeed in leaving the needle floating on the surface of the water.

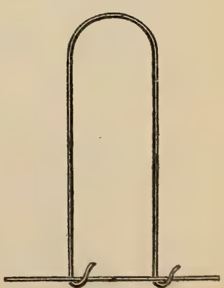


FIG. 56.

What is the form of the water surface around the needle ?

Break the surface of the water near the needle by thrusting a finger into the water. What takes place ?

Experiment 2.

Magnetise a sewing needle by rubbing it with a permanent magnet (Experiment 5, page 58), and place it on the surface of the water as in the last experiment.

In what direction does the needle set itself?

Place another magnetized needle on the surface of a soap solution.

What position does this needle take on the surface?

The superficial film of a liquid is more viscous than the interior. This film therefore is hard to break, and bodies which would naturally sink if placed in the interior of the liquid are borne up by it.

3. Surface Tension.

Experiment 3.

Let water fall in drops from the end of a glass rod. Let some of the drops rest on a greased surface. Place a few drops of mercury on a table.

1. What is the shape of the drops of water when falling through the air? What when on the greased surface?
2. What is the shape of the drops of mercury?
3. How is small shot made?

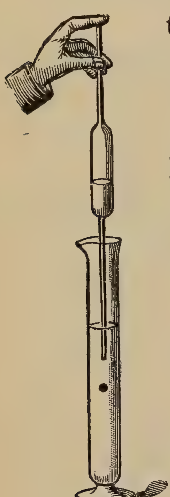


Fig. 57.

Experiment 4.

Soften the end of a stick of sealing wax or of a glass rod by heating it.

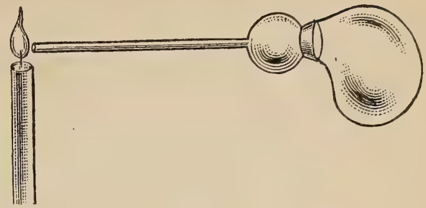
What shape does it take?

Experiment 5.

Make a mixture of alcohol and water of the same density as olive oil. This is most quickly done by the use of a hydrometer. With a pipette introduce some of the oil into the centre of the mixture (Fig. 57).

What shape does it assume?

Experiment 6.



Make a soap solution, and with a thistle-tube blow a bubble. When the bubble has become fairly large, remove the end of the tube from the mouth and place it near the flame of a lighted candle (Fig. 58).

FIG. 58.

What takes place?

Experiment 7.

Dip the mouth of a glass funnel into the soap solution, and, keeping a finger over the narrow end, lift the funnel out of the solution and observe the film on the mouth of the funnel.

Remove the finger from the narrow end.

What change takes place in the film?

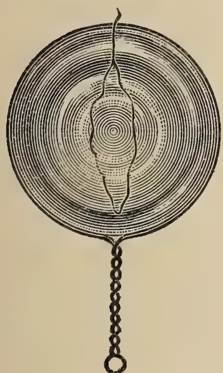


FIG. 59.

Experiment 8.

Make a ring of stout wire about 10 cm. in diameter with a handle and tie to the ring a loop of thread as shown in Fig. 59. Dip the ring into the soap solution and withdraw it, carrying with it a soap film formed across it. Now break the film within the loop of thread by piercing it with a hot wire.

Describe what takes place.

The experiments in this and the preceding section tend to show that the surface film of a liquid acts as if it were a thin, elastic skin,[1] somewhat tough and viscous, stretched tightly over the liquid.

[1] Though the surface of a liquid behaves, in general, like a stretched elastic membrane, it nevertheless differs from such a membrane in two important particulars, namely, that liquid films, when unrestrained, contract indefinitely; and, secondly, the tensile force is the same in all directions and independent of the thickness, at least when the latter exceeds a certain very small value.—*Text-Book of General Physics, by Chas. S. Hastings & Fred. E. Beach.*

The stress which exists in the surface film of a liquid is called **surface tension.**

This tension is shown in the tendency of the surfaces of the drops of water, mercury and oil, and of the ends of the heated glass and sealing wax rods to assume a minimum area in the spherical form (Exps. 3-5), as well as in the tendency of the soap film to contraction (Exps. 6-8).

4. Capillarity.

Experiment 9.

Dip a clean glass plate into (*a*) water, (*b*) mercury.

1. Make drawings of vertical sections of the surfaces of the water and the mercury around the plate.

2. Does the water wet the plate? Does the mercury?

3. The adhesion between the water and the glass is greater than the cohesion in the water, and the cohesion in mercury is greater than the adhesion between the mercury and the glass. How does this explain the difference in the position of the liquid surfaces around the plate?

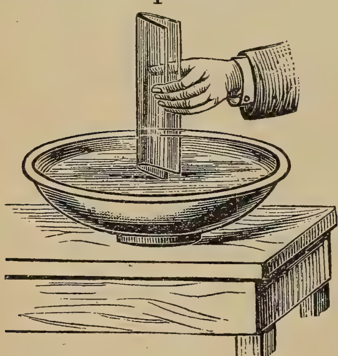


FIG. 60.

Experiment 10.

Hold two glass plates with the edges together at one side, but kept a little apart at the other (Fig. 60). Place the plates vertically in (*a*) water, (*b*) mercury.

Make drawings showing the position of the surfaces of the water and of the mercury on the outside of the plates and between them.

Experiment 11.

Dip vertically into (*a*) water, (*b*) mercury, a glass tube the bore of which is about one millimetre in diameter.

1. Does the water or the mercury rise in the tube? Is either depressed?

2. What is the form of the surface of (*a*) the water, (*b*) the mercury in the tube?

Repeat the experiment, using tubes of smaller bore.

In which is there the greatest difference in level between the surface of the liquid in the vessel and its surface in the tube?

Experiment 12.

Take two capillary tubes of the same bore, place one in alcohol and the other in water.

Does the water rise to the same height in the one tube as the alcohol does in the other?

Experiment 13.

Take two capillary tubes of the same bore, dip one into any liquid and the other into the same liquid at a higher temperature.

In which is the difference of level between the liquid within the tube and that without the greater?

Phenomena of the kind illustrated in the foregoing experiments are known as **capillary phenomena,** because they take place in tubes with capillary or hair-like openings.

5. Laws of Capillarity.

1. **Liquids rise in tubes when they wet them, and are depressed when they do not.**

2. **The ascension or depression is inversely as the diameter of the bore of the tube for the same liquid, but differs with different liquids.**

3. **The ascension and depression increases when the temperature of the liquid decreases.**

Experiment 14.

Take tubes of the form shown in Figure 61; pour water into one and mercury into the other.

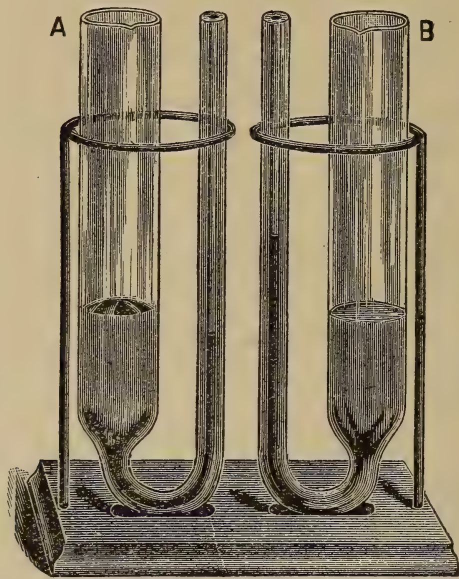


FIG. 61.

Account for the forms of the surfaces and the differences in level observed.

Experiment 15.

Place (*a*) one corner of a lump of sugar in water; (*b*) the corner of a sheet of blotting-paper in ink; (*c*) the end of a piece of loosely woven cloth, such as a lamp-wick, in water.

What takes place in each case?

Porous bodies, such as blotting-paper, wood, cloth, etc., absorb liquids by capillary action, the liquid rising in the irregular spaces within the bodies.

6. Will a Liquid Overflow a Tube by Capillary Action?

Experiment 16.

To answer this question, take a tube of very fine bore, place one end of it in water and hold it in a vertical position until

the water rises to a considerable height in it, then depress it until the upper end comes near the surface of the water.

What change takes place in the height of the liquid within the tube as it is depressed?

Surface viscosity, surface tension and capillarity must not be regarded as isolated phenomena. They are intimately connected and are apparently due to the tendency to balance or equilibrium among the molecular forces of cohesion and adhesion under varying conditions. The reasoning usually offered in explanation of their causes and relations does not come within the scope of this work.

IV.—Transmission of Pressure by Fluids.

7. In what Direction is Pressure Transmitted by Liquids?

Experiment 1.

Take a small rubber bulb used in compressing air for working a camera shutter or atomizer (Fig. 62), and prick holes in it with a large pin at various points in its circumference. Fill it with water and cork the opening in it with a glass rod or pencil. Now squeeze the bulb between the thumb and finger.

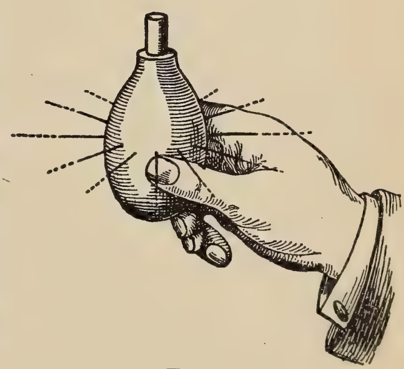


FIG. 62.

1. Describe what takes place.

2. What does this prove with regard to the direction in which the water within the bulb transmits the pressure applied to its surface?

8. Law of Transmission of Fluid Pressure—Pascal's Principle.

Experiment 2.

Arrange apparatus as shown in Fig. 63. Partially fill the U-shaped tubes with mercury. Fill the bulb and tube with

water. Now mark with a thin rubber band the height of the mercury in the outer branch of each of the U-tubes, and place

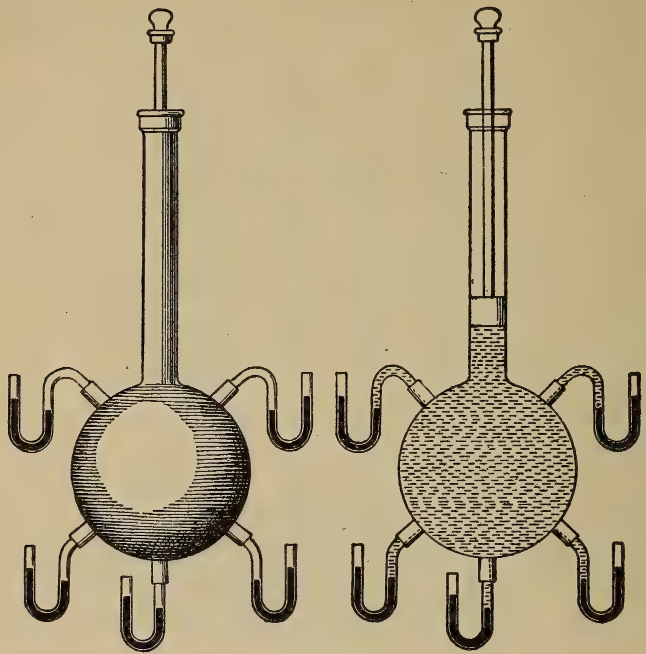


Fig. 63.

a rubber band on each **at the same distance** above that which marks the surface of the mercury. Carefully insert the piston into the tube, and push it down until the mercury in one of the tubes reaches the upper band.

1. Where does the mercury stand in each of the other tubes?
2. What has caused the change in level of the mercury in the tubes?
3. What additional fact does this experiment prove with regard to the transmission of pressure by liquids?

Experiments 1 and 2 tend to show that **pressure exerted anywhere upon a mass of fluid is transmitted undiminished in all directions, and acts with equal intensity upon all equal surfaces, and in directions at right angles to these surfaces.**

This is generally known as **Pascal's Principle**.

Experiment 3.

Pour a small quantity of mercury into a tube of the form shown in Fig. 64. Now pour some water into the larger branch.

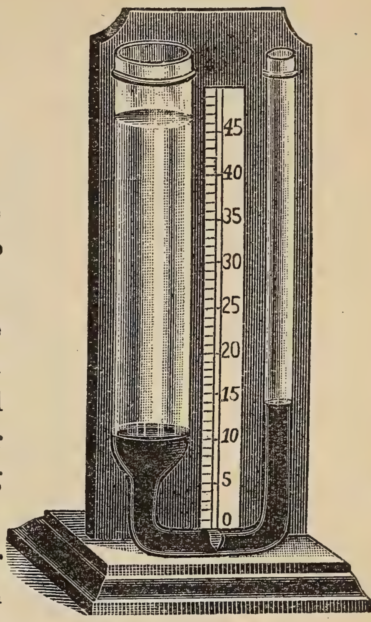


Fig. 64.

1. What changes take place in the levels of the mercury in the two branches? Why?

2. How much water do you suppose must be put into the smaller branch to bring the mercury to the same level in each branch? Give reasons for your answer. Verify by pouring water into the smaller branch.

3. How does the weight of the water in the large branch compare with that in the smaller one when the mercury is restored to the same level in each tube?

9. Mechanical Application—Hydrostatic Press.

The equal transmission of fluid pressure is the principle upon which all hydrostatic presses are constructed.

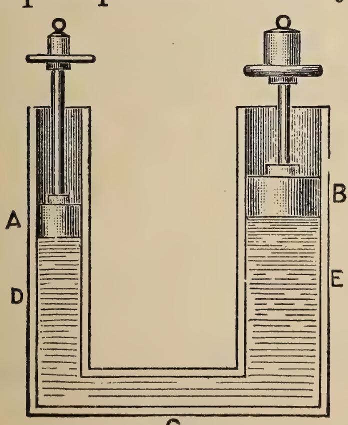


Fig. 65.

Fig. 65 represents one of the simplest forms of these presses. D and E are two hollow cylinders connected by a tube C, and partly filled with water; A and B are two pistons fitted into D and E respectively. Any force applied to A is transmitted through the fluid to B, and the pressures upon A and B are in the ratio of the areas. Thus, if the area of A is one square inch when that of B is ten

square inches, a weight of one pound placed upon A will sustain a weight of ten pounds placed upon B.

10. Hydrostatic Paradox.

By decreasing the area of A indefinitely and increasing that of B indefinitely, any force however small, applied to A may, by the transmission of pressure through the fluid, be made to support upon B any weight however large. This is sometimes called a "**Hydrostatic Paradox.**"

V.—Pressure due to Weight.

11. Relation between Pressure and Depth.

Experiment 1.

Cut the funnel-shaped end from a thistle tube, leaving about half an inch of the stem connected with it. Cement across the mouth of the funnel a piece of thin sheet rubber. This may be done by warming the lip of the funnel and pressing it down first on a cake of beeswax-resin cement and then on the sheet rubber. Procure a U-shaped tube, which for convenience in emptying, should have an offset at the bottom closed with a rubber tube and pinch-cock. Connect the U-tube by means of a short rubber tube and a long bent glass tube with the funnel, and support the whole at such a height above the table that a tall glass jar can be slid under the mouth of the funnel (Fig. 66).

Partially fill the U-tube with water and press the rubber membrane with the finger.

1. What change takes place in the position of the water in the tube? Why?

2. How is (*a*) an increase, (*b*) a decrease in the pressure on the membrane indicated by the water in the tube?

3. How does the tube when filled act as a pressure-gauge?

Allow the water to run out of the pressure-gauge. Fill the jar with water, place it under the funnel and raise it up until

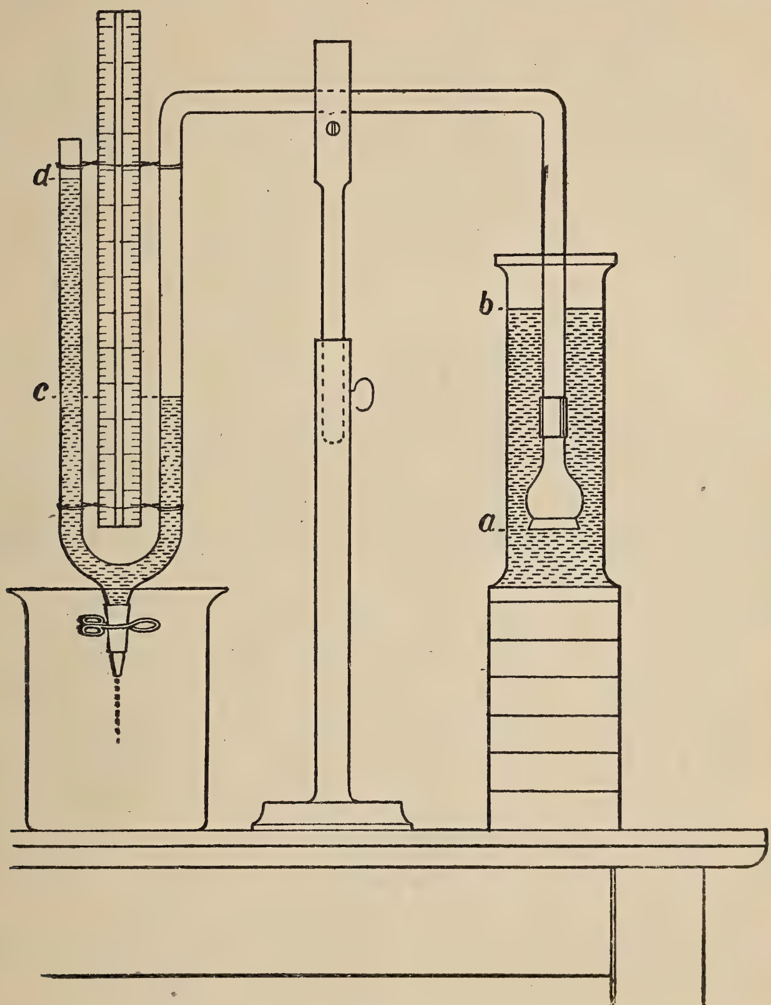


FIG. 66.

its bottom is near the mouth of the funnel. Support it in this position upon a series of blocks. Observe the shape of the rubber membrane.

What is the cause of the change in shape?

Pour water into the pressure-gauge until the membrane resumes its original plane contour. Now measure with a

scale, (1) the depth *ab* of the membrane below the surface of the water, (2) the difference in level *cd* of the water in the limbs of the pressure-gauge.

Remove the supporting blocks one at a time. After the removal of each block adjust the water level in the pressure-gauge and take the measurements noted above. Tabulate the results thus:

DEPTH.	READING OF PRESSURE-GAUGE.

Plot a curve showing the relation of pressure to depth.

12. Is the Pressure Within a Liquid Mass Equal in all Directions at the Same Depth?

Experiment 2.

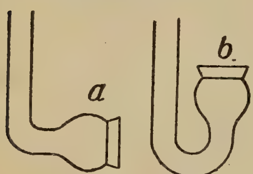


FIG. 67.

To answer this question repeat Experiment 1, making the funnel face instead of downwards, (*a*) sideways, (*b*) upwards, as shown in Fig. 67. Adjust the height of the jar for each measurement so that the depth of the **centre** of the membrane will be the same as for the corresponding reading in Experiment 1.

Tabulate and compare the results with the results obtained in Experiment 1.

What does this comparison indicate with regard to the magnitude of the pressure in different directions on the membrane when it is kept at the same depth?

13. Relation Between Pressure and Density.

Experiment 3.

Repeat Experiment 1, using instead of water in the jar (but not in the pressure-gauge) another liquid, say alcohol or

a solution of salt in water, whose density has been determined by the method indicated in Experiment 5, page 71.

Adjust the height of the jar for each measurement so that the depth of the membrane may be the same as for the corresponding reading in Experiment 1.

Tabulate the results thus :—

DEPTH.	RATIO OF READINGS OF PRESSURE-GAUGE IN EXPERIMENTS 1 AND 3.

1. Are the ratios indicated above approximately the same for the different depths ?

2. How does the average ratio compare with the ratio of the density of water to the density of the liquid used ?

14. Relation of Rate of Pressure to the Mass of the Liquid Pressing When the Depth is Constant.

Experiment 4.

Connect a U-shaped glass tube A with a collar B into which

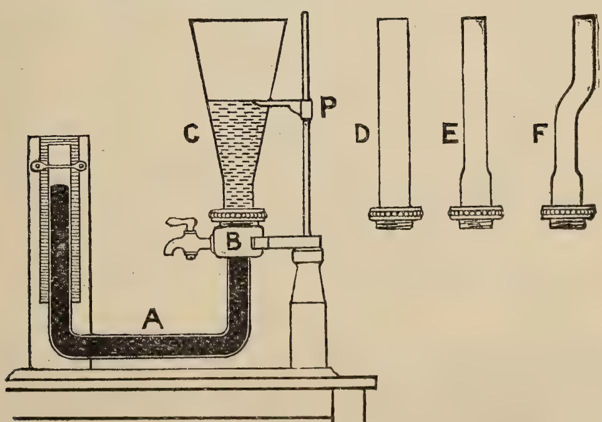


FIG. 68.

can be screwed tubes of different shapes, C, D, E, F. Pour mercury into the U-tube until it reaches nearly up to the

collar. Screw one of the tubes, say C, into the collar and fill it with water up to any height indicated by a pointer P. Note the height of the mercury in the open limb of the U-tube. Now replace the tube C by each of the others in succession, filling them to the same height and noting the height of the mercury in the U-tube.

Compare for the different cases (*a*) the pressures on the surface of the mercury due to the water poured into the tubes, (*b*) the masses of the water pressing.

The above experiments tend to demonstrate the following laws:

1. **The pressure within a liquid mass increases from the surface downwards in direct proportion to the depth.**

2. **The pressure at a given depth below the surface is proportional to the density of the liquid.**

3. **The pressure in a given liquid is dependent only upon the depth. It is independent of the form of the vessel and of the amount of liquid which it contains.**

VI.—Surface of a Liquid at Rest Under the Action of Gravity.

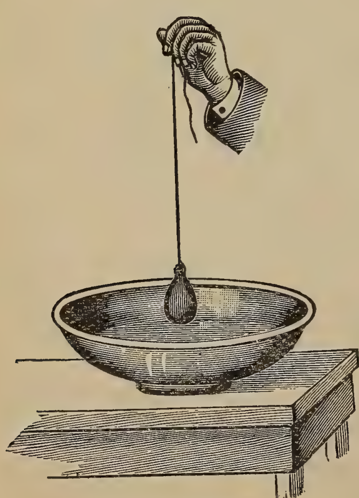


Fig. 69.

Experiment 1.

Pour enough mercury into a bowl or a dinner plate to cover its bottom. Hold a plumb-line over the surface of the mercury (Fig. 69).

1. What direction does a plumb-line always take?

2. What direction does the image of the line take with regard to the line itself?

3. What then must be the position of the surface of the mercury?

Experiment 2.

Pour water into a series of connecting tubes of various sizes and shapes. An apparatus for this purpose can be made by cutting the bottom off a glass bottle, inverting it and inserting tubes through a cork as shown in Fig. 70. Very small tubes should not be used.

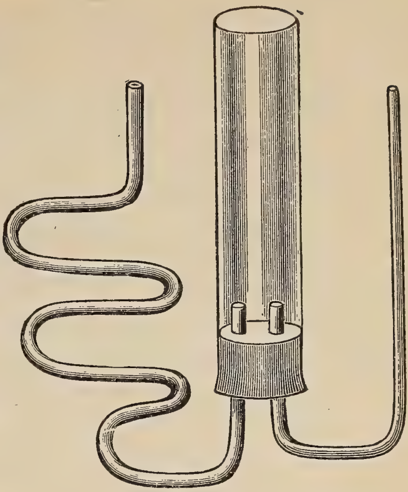


FIG. 70.

1. Does the water reach the same level in each tube?

2. What would be the result if some very small tubes were used?

The surface of a liquid at rest is horizontal.

VII.—Buoyancy.

15. Nature of Buoyancy.

Experiment 1.

Lower several bodies, such as pieces of stone, iron, glass, wood, etc., into water by tying pieces of elastic to them (Fig. 71).

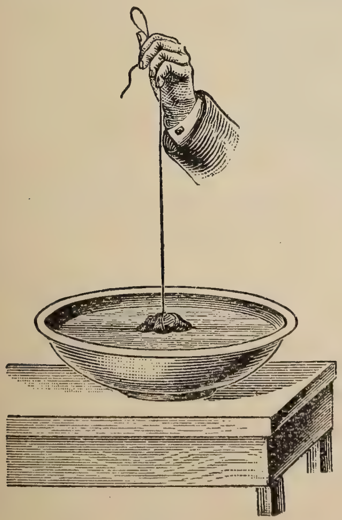


FIG. 71.

1. What change takes place in the tension of the elastic as the bodies enter the water?

2. What is the effect of the pressure of water on a body immersed, to lift it up or depress it?

3. Why should the water produce this effect?

To answer this question consider:

(*a*) Which is the deeper in the water, the upper or the lower surface of the body?

(*b*) Upon which surface then will the pressure of the water be the greater?

The resultant pressure exerted by a fluid on a body immersed in it is known as the **buoyancy** of the fluid.

16. What is the amount of the buoyant force which a liquid exerts on an immersed body?

Experiment 2.

To answer this question, take a brass cylinder A, which fits exactly into a hollow socket B. Hook the cylinder to the bottom of the socket and counterpoise them on a balance. Surround the cylinder with water (Fig. 72).

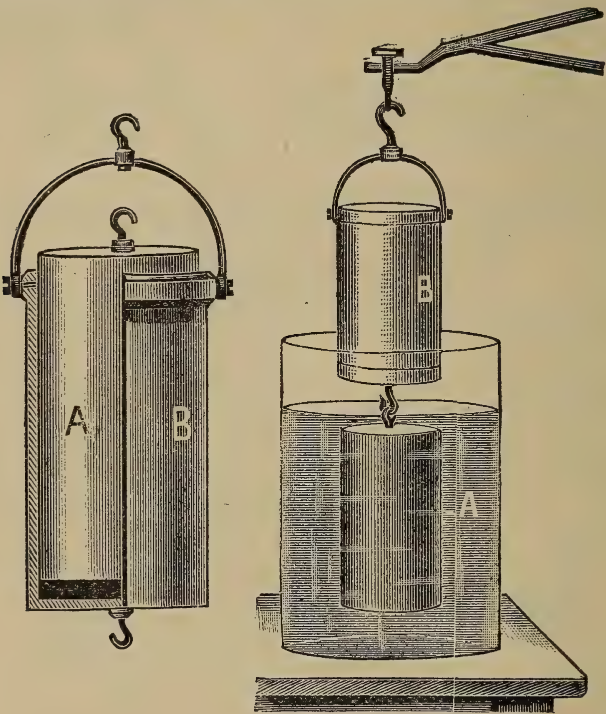


FIG. 72.

What change takes place in the equilibrium of the balance?

Now pour water into the socket until the equilibrium is restored.

1. When does this take place?

2. How does the volume of the water in the socket compare with the volume of the cylinder?

3. By the weight of what volume of water then was the cylinder buoyed up?

4. Is the mutual attraction between the earth and A lessened by surrounding it with water?

17. Law of Buoyancy—Principle of Archimedes.

The buoyant force exerted by a fluid upon a body immersed in it is equal to the weight of the fluid displaced by the body; or a body when weighed in a fluid loses in apparent weight an amount equal to the weight of the fluid which it displaces.

This is known as the **principle of Archimedes.**

18. Flotation.

Experiment 3.

Partially fill a graduated tube with water and place on the surface of the water in the tube a piece of wood which has been weighed.

1. What is the volume of the water displaced by the wood?

2. What then is the weight of the water displaced by the wood?

3. How does the weight of the wood compare with the weight of the water displaced by it?

4. To what is the buoyant force of water on the wood equal?

5. When will a body sink? When float?

Experiment 4.

Try to float an egg in (*a*) fresh water, (*b*) a saturated solution of common salt.

1. What difference do you observe in the position of the egg?

2. How does an increase in the density of a liquid affect its buoyancy? Why?

3. Will a body whose density is one gram per cubic centimetre sink or float in water? Why?

QUESTIONS.

1. Why will an iron ship float on water while a piece of solid iron sinks?

2. Why do birds float high on water?

3. Why does oil float on water while mercury sinks?

4. Will air float on water?

5. Pour into the same test-tube (*a*) mercury, (*b*) a saturated solution of carbonate of potash in water, (*c*) alcohol coloured with a few drops of red ink, (*d*) coal oil. Cork the tube, shake it, and allow it to stand for a few seconds. What positions do the liquids assume? Why?

6. Release a cork which you are holding at the bottom of a vessel filled with water. What happens? Has the cork any power in itself to rise? If not, what causes the movement?

7. A cork which weighs 5 grams is tied to the bottom of a beaker which weighs 5 grams. If water weighing 50 grams is poured into the beaker, and the beaker and its contents placed on the scale-pan of a balance, what weight placed in the other scale-pan should balance it? Why?

8. A piece of coal is placed in one scale-pan of a balance and iron weights are placed in the other scale-pan to balance it. How would the equilibrium be affected if the balance, coal, and weights were now placed under water? Why?

9. A canoe and the person in it weigh 275 pounds, what weight of water is displaced by the canoe when floating with the person seated in it? If the person presses on one side of the canoe, what change will take place in the weight of the water displaced? Why?

10. What must be the weight of a piece of cork which will displace 10 grams of alcohol when floating on alcohol?

CHAPTER VIII.

PROPERTIES AND LAWS OF GASES.

I.—Gaseous Pressure.

1. Has a Gas Weight?

Experiment 1.

Take a vessel A (Fig. 73), which can be attached to an air pump, weigh it, exhaust the air from it, close the stop-cock, and weigh it again.

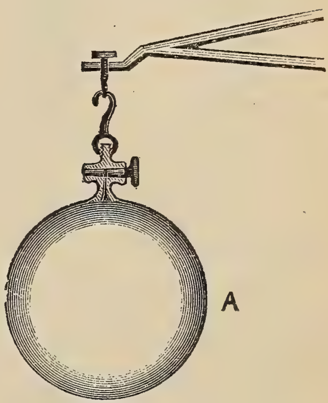


FIG. 73.

1. What difference in weight is observed?

2. What causes this difference?

Allow the air to re-enter and observe the result.

3. Has air weight?

Gases, like solids and liquids, possess Weight.

2. Pressure Due to Weight.

We have seen that, on account of their weight, solids exert pressure on the bodies which support them, and liquids exert pressure on all bodies in contact with them. **Do gases exert pressure?**

Experiment 2.

Tie a piece of sheet rubber over the mouth of a thistle-tube and exhaust the air from the tube by suction, or by connecting it by means of a piece of heavy rubber tubing

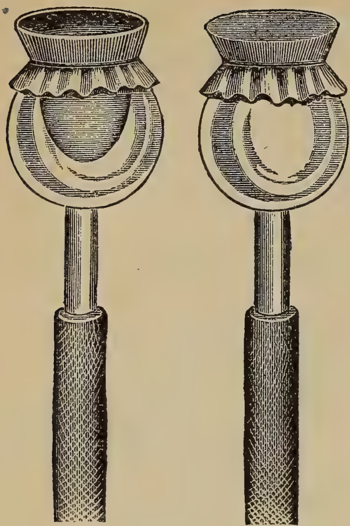


Fig. 74.

with an air pump or an aspirator (Fig. 74).

1. What change takes place in the position of the rubber membrane?

2. What causes this change?

Turn the tube so that the membrane may face upwards, downwards, and in various directions.

1. Does the position of the membrane change as the tube is turned in different directions?

2. What does this prove with regard to the intensity of the pressure of the air in different directions at the same point?

Experiment 3.

Place a receiver on the plate of an air pump, and exhaust the air from the receiver (Fig. 75).

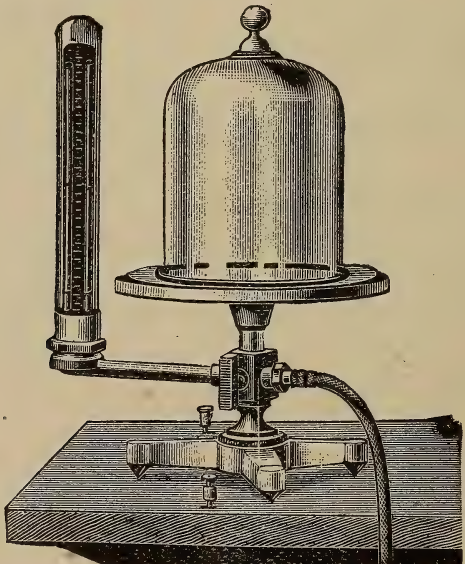


Fig. 75.

Try to separate the receiver from the plate.

1. What evidence have you that the air on the outside of the receiver presses downward upon it?

2. What evidence have you that the air which was within the receiver exerted an upward pressure on it?

3. Pressure due to the Expansive Force of a Gas.

We have seen (Art. 8, page 37) that gases tend to expand indefinitely, and that they consequently exert pressure on the surfaces of the vessels that contain them. This action may be illustrated by additional experiments.

Experiment 4.

Fill a bottle partly full of water, cork it with a perforated cork and connect it by a bent tube with an uncorked bottle, as shown in Fig. 76. Place both bottles under the receiver of an air pump and exhaust the air from the receiver.

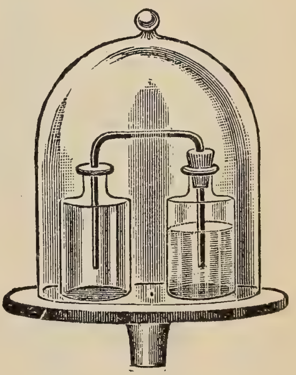


FIG 76.

1. What movement takes place in the water?

2. What must have caused it?

3. Why did not this force cause the movement in the water before the air was exhausted from the receiver?

Let the air into the receiver again.

What takes place? Why?

Experiment 5.

Place a shrivelled apple under the receiver of the air pump and exhaust the air. Let the air into the receiver rapidly.

What changes in the appearance of the apple take place? Give reasons for them.

Experiment 6.

Place together the two hollow metal hemispheres, known as

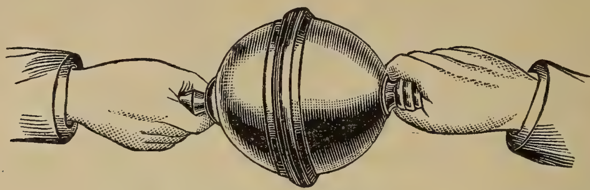


FIG. 77.

the Magdeburg Hemispheres (Fig. 77), having carefully cleaned and greased the edges. Close the tap.

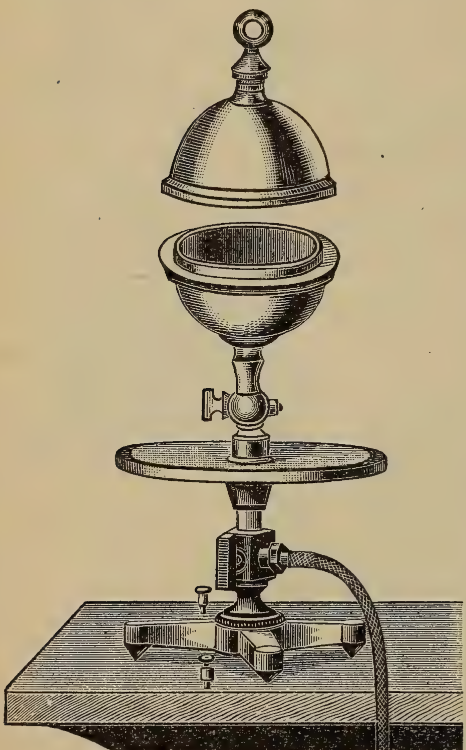


FIG. 78

Has the air shut up within them any expansive force?

To answer this question, screw the apparatus to the air pump, open the tap, and exhaust some of this air (Fig. 78). Close the tap and try to separate the hemispheres.

1. What evidence have you now that the original air shut up within the hemispheres exerted an outward pressure upon their internal surfaces?

2. Why was this pressure not evident at first?

3. How does decreasing the density of a gas affect its expansive force, all other conditions remaining the same?

Experiment 7.

Take a long glass tube A closed at one end and fitted at the other with a stop-cock which screws into the plate of an air

pump. (The tube known as the Guinea-and-Feather Tube answers well.) Stand the tube in a vertical position, with the open end of the tap in water (Fig. 79). Open the tap.

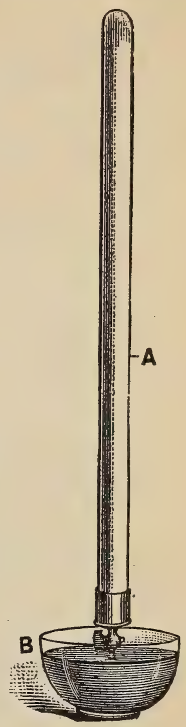


FIG. 79.

Does the water rise in the tube?

Take the tube out of the water, screw it to the air pump and partially exhaust the air, close the tap, unscrew it from the pump and place it as before in water. Open the tap.

1. What is the cause of the movement in the water?

2. Did the pressure which caused this movement exist before the air was removed from the tube? If so, why did not the movement take place?

3. Is this pressure and the expansive force of the air within the tube equal when the water comes to rest? Give reasons for your answer.

4. When the tube was placed in the water and the tap opened, what change took place in (*a*) the density of the air remaining in the tube, (*b*) its mass, (*c*) its expansive force?

Experiment 8.

Take a glass tube or a quill about four inches long and stop each end by piercing a freshly-cut slice of potato with it. With a small ramrod push one of the pieces of potato forward in the tube.

1. What takes place?

2. What is the cause of the phenomena observed?

The experiment illustrates the principle of air-guns, in which the expansive force of compressed air is made use of to project missiles. On account of the expansive force which compressed air exerts, it is also the source of

power in a great variety of mechanical operations. For example, it is now used almost exclusively for applying the breaks in railway carriages, and it is being extensively employed to operate small portable tools such as hammers, drills, etc.

The power is usually applied through a motor, which, in its simplest form, consists of a piston made to move to and fro in a cylinder by the expansive force of the air applied alternately to its two faces.

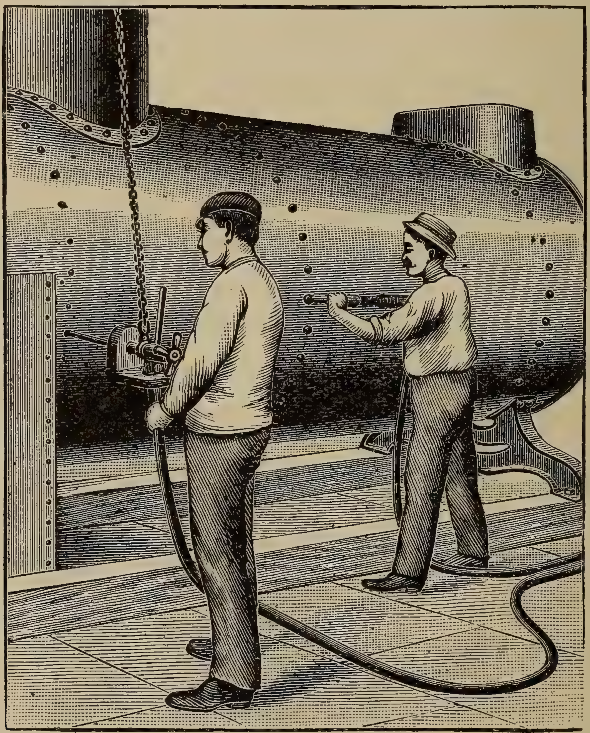


Fig. 80.

Fig. 80 shows a drill and a hammer operated by compressed air being used in the construction of a boiler.

4. Buoyancy of Gases.

Experiment 9.

Hang a hollow metal or glass globe A from one end of a short balance beam and attach a weight B to the other end of the beam to restore equilibrium. Place the balance under the receiver of an air pump and exhaust the air (Fig. 81.)

1. What change in the position of the balance beam takes place?

2. What effect must the air have had on the globe?

3. Did it have the same effect on the weight upon the other end of the beam?

4. Account for what takes place when the air is exhausted.

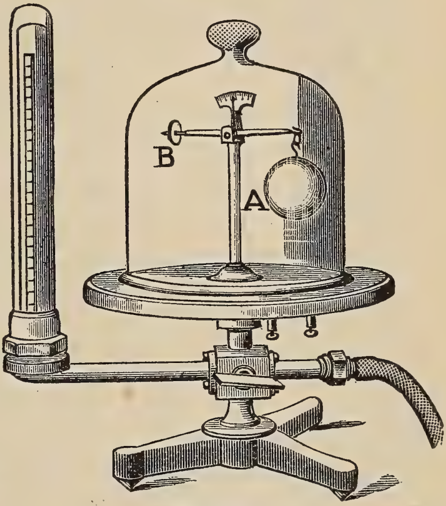


FIG. 81.

1. **Gases, like liquids, on account of their weight, exert pressure on the surfaces of bodies immersed in them, and this pressure is equal in all directions at the same point.**

For example, the gas (air) constituting the atmosphere, which surrounds the earth, on account of its weight presses down on the surface of the earth and upon everything on it, just as the water of the ocean presses down on the ocean bed and upon bodies resting on it.

2. **Gases, on account of their tendency to expand indefinitely, exert an expansive force, which is of equal intensity at all points both within the mass of the gas itself and upon the internal surface of the vessel which contains it.**

This pressure is sometimes known as the **tension** or **elastic force** of the gas.

3. **A gas, like a liquid, exerts upon any body immersed in it a buoyant force which is equal to the weight of the gas displaced by the body.**

5. Measure of the Rate of Pressure of the Atmosphere—The Barometer.

The pressure of the atmosphere may be measured as other forces often are, by measuring some counterbalancing force.

FIG. 82

Experiment 10.

Connect a glass tube A closed at one end with another B of the same size, but open at both ends, by a piece of stout rubber tubing C (Fig. 82). Each glass tube should be about 80 cm., and the rubber tube about 15 cm. in length and 4 mm. in diameter. Hold the tubes in the position shown at the left hand, and fill A and the rubber tube with mercury. Now invert A and place the connected tubes in the position shown at the right hand, thus forming a U-shaped tube, of which the branches are A and B.

1. What is the length of the column of mercury in A above the level of the mercury in B?

The weight of this column of mercury is just balanced by the weight of the column of air pressing on the surface of the mercury in B. Hence the pressure of the air on the surface of the mercury in B may be measured by the weight of the mercury in A above the level of the mercury in B.

1. What is the length of the column of air which weighs the same as the column of mercury in A above the level of the mercury in B?

2. What transmits the air pressure on the surface of the mercury in B to column of mercury sustained by it?

3. Devise an experiment to show that the column of mercury in A is sustained by the pressure of the air on the surface of the mercury in B.

4. If the tubes A and B were of different diameters, would the difference in levels of the mercury in the two tubes be the same as in this case, where the tubes are of equal diameter? Why?

A tube of this form permanently mounted and supported with scales for determining the differences in level between the mercury in the two branches is one form of the **barometer**, an instrument used for determining the pressure of the atmosphere. Fig. 83 shows a barometer of this form.

The upper scale gives the height of the mercury in the closed branch above a fixed point, and the lower scale the distance of the mercury in the open branch below the same fixed point. The sum of the two readings is the height of the barometer column.

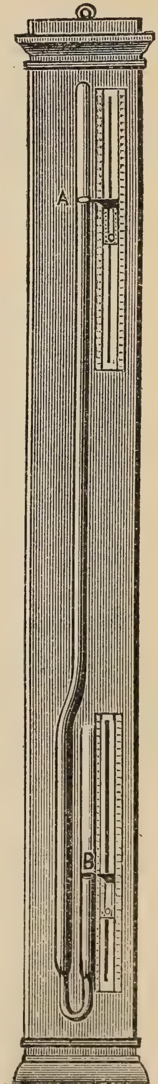


Fig. 83.

Instead of a U-shaped tube, a straight tube is frequently used to contain the mercury in measuring the pressure of the atmosphere.

Experiment 11.

Take a glass tube, about one centimetre in diameter and 80 centimetres long, closed at one end, fill it with mercury and, stopping the open end with the finger, invert it and place it in a vertical position with the open end under the surface of the mercury in another vessel (Fig. 84).

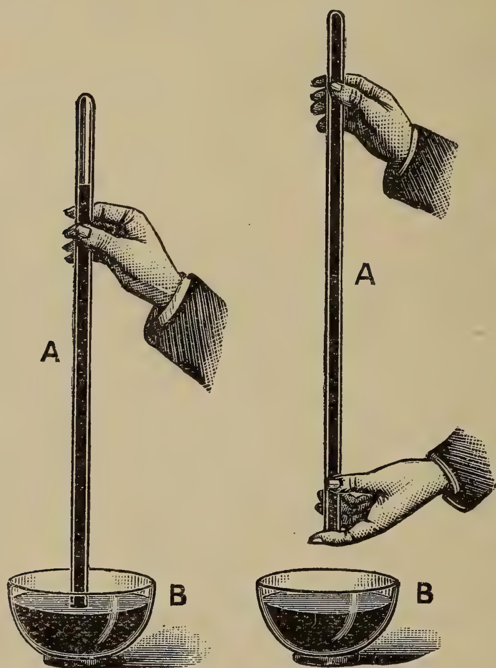


FIG. 84.

1. What takes place when the finger is removed? Explain the reason. See Experiment 7, page 110.

When a straight glass tube is used as a barometer, the cistern which contains the mercury has usually a flexible leather bottom which can be moved up or down by a screw C. A scale is attached to the

side of the tube by means of which the height of the surface of the mercury in the tube above a fixed point in the cistern may be observed.

To read the barometer the screw C is turned until the surface of the mercury in the cistern comes to the fixed point. The scale will then indicate the difference in the mercury levels in the tube and the cistern.

FIG 85.

1. Upon what does the air press which sustains the column of mercury?

2. Would the height of this column be changed if the tube were not of uniform bore? Why?

3. What change in the height of the column would indicate an increase in the pressure of the atmosphere? What change a decrease? Why?

4. What is there in the tube above the mercury?

5. What effect would be produced by admitting a little air into this space? What force produces this effect?

6. Which would be the more suitable for an accurate barometer, a tube of fine bore or one of wide bore? Explain.

7. Explain why a barometer falls when carried up a mountain.

II.—Compressibility of Gases.

We have seen (page 37) that gases are compressible. **What is the relation between the volume and the pressure of a gas?**

Experiment 1.

Take a tube about 25 cm. long and at least 4 mm. in diameter, one end of which is closed by a stop-cock. A thistle-

tube supplied with a stop-cock answers well. Connect this by means of a heavy rubber tube not less than 50 cm. long with

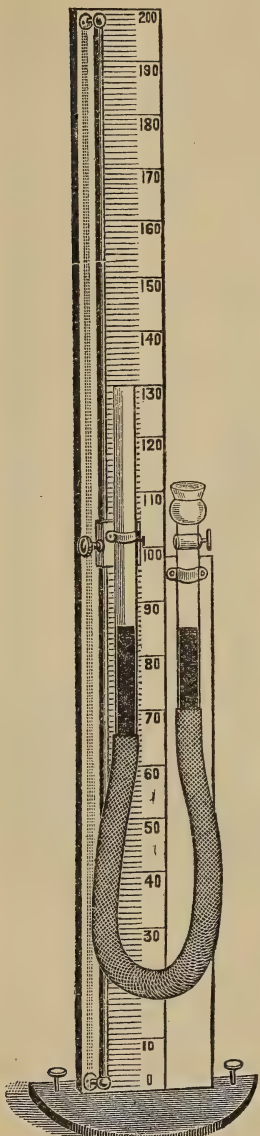


FIG. 86.

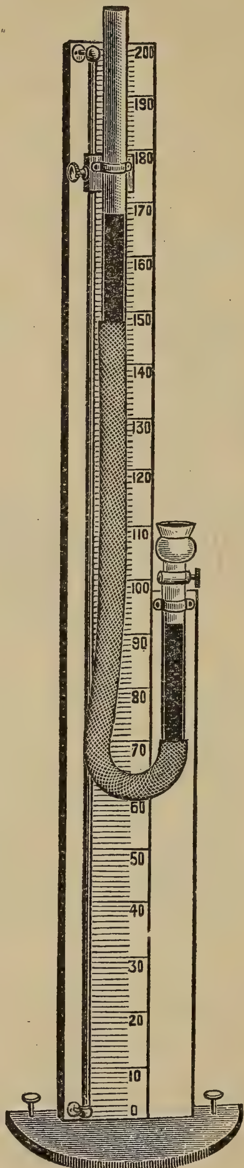


FIG. 87.

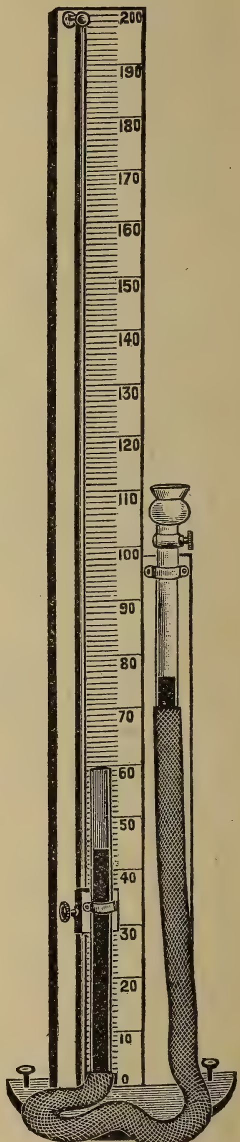


FIG. 88.

a glass tube, also about 50 cm. long. The joints should be wrapped with fine wire or string. Place the tube in a support

as shown in Fig. 86, open the stop-cock and pour mercury into the connected tubes until it reaches the same level at or near the centre of each glass tube. Close the stop-cock. Take the reading of the barometer.

Height of barometer (H)= ?

The pressure to which the enclosed air is subjected is measured by,

(1) The barometric reading (H)
when the mercury surfaces are at the same level. Why?

(2) The barometric reading (H)± the difference between the levels of the mercury surfaces
when these surfaces are not at the same level. Why?

The plus sign is to be taken when the mercury in the open tube is higher, and the minus sign when it is lower than in the closed tube. Why?

Place the open tube in several positions with the surface of the mercury in it either above (Fig. 87) or below (Fig. 88) the surface of the mercury in the closed tube; and measure

(1) The lengths of the air column in the closed tube;

(2) The vertical distances between the mercury levels in the two tubes.

Supposing that V represents the original volume of the enclosed air and H the reading of the barometer; and that V_1, V_2, V_3, V_4, etc., represent the volumes of this air at successive observations; and that H_1, H_2, H_3, H_4 represent the differences in mercury levels for these observations, fill up the following table;

VOLUMES.	PRESSURES.	PRODUCTS
$V =$	$P = H \quad =$	$V \times P =$
$V_1 =$	$P_1 = H \pm H_1 =$	$V_1 \times P_2 =$
$V_2 =$	$P_2 = H \pm H_2 =$	$V_2 \times P_2 =$
$V_3 =$	$P_3 = H \pm H_3 =$	$V_3 \times P_3 =$
$V_4 =$	$P_4 = H \pm H_4 =$	$V_4 \times P_4 =$
Etc.	Etc.	Etc.

If the experiment is carefully performed, the products $V \times P$, $V_1 \times P_1$, etc., will be found to be equal. This being the case, it is evident that the volume of the air is decreased at exactly the same rate as the pressure is increased, or is increased at the same rate as the pressure is decreased. That is, the volume of a given portion of air varies inversely as the pressure to which it is subjected.

The extended researches of careful experimenters have shown that all gases, within certain limitations, conform to this law.

The law is known as Boyle's or Mariotte's Law. It may be thus stated:

6. Boyle's or Mariotte's Law.

If the temperature is kept constant, the volume of a given mass of gas varies inversely as the rate of pressure to which it is subjected.

The gases which most closely follow this law are those which are farthest removed, both as to temperature and pressure, from their points of liquefaction.

When a gas nears its liquefying point, the reduction in volume is greater than that which the law would indicate.

QUESTIONS.

1. If the volume of the air shut up in the tube, Experiment 1, page 117, is 10 c.cm. when the mercury is at the same level in each tube and the barometer stands at 70 cm., what will be the difference in level between the surfaces of the mercury in the tubes when the volume of this air occupies (*a*) 5 c.cm., (*b*) 20 c.cm.?

2. The differences in levels, Experiment 1, page 117, at four different observations are 10 cm., 90 cm., 170 cm., 250 cm., and the volume of the enclosed air at the first observation was 12 c.cm., what was the volume of the air at each of the other observations if the barometer stands at 70 cm.?

3. What effect would (*a*) raising, (*b*) lowering, the open tube, Experiment 1, page 117, have upon (1) the mass, (2) the density, (3) the expansive force of the enclosed air?

4. The pressure of a gas is 10 grams per sq. cm. when its volume is 100 c.cm., what is the pressure when the volume is 150 c.cm.?

5. The volume of gas shut up in a rubber bag is 200 c.cm. when the barometer stands at 70 cm., what will be the volume of the gas when the barometer stands at 80 cm.?

6. If a gas occupies a volume of 25 c.cm. when the barometer stands at 76 cm., what must be the reading of the barometer when the gas measures 30 c.cm.?

7. A gas holder contains 22·4 litres of a gas measured when the barometer stands at 72 cm., what will be the volume of the gas when the barometer stands at 76 cm.?

8. A rubber bag contains 100 c.cm. of air at the atmospheric pressure, what will the volume of the air become if the bag is sunk to a depth of 30 feet in water? What would be the buoyant force of the water upon it? The water barometer stands at 30 feet.

9. Why is compressed air used in (*a*) bicycle tires, (*b*) air-cushions.

III.—Instruments and Machines.

7. Air Pump.

The air pump is used for removing the air from enclosed vessels.

Fig. 89 shows one of the most common forms of the air pump. A cylindrical barrel AB is connected by means of a pipe C with a receiver R, from which the air is to be removed. A piston D, in which there is a valve opening upward, is worked in the barrel by a rod which passes through the air-tight collar at the top of the barrel. At A and B, the ends of the barrel, are valves opening upward. A gauge G for testing the extent of the exhaustion is sometimes connected with the tube C by means of a tap T.

Suppose D at its lowest position. As it ascends, the compression of the air in AD closes the valve in the piston (Fig. 89) and opens the valve A, and the enclosed

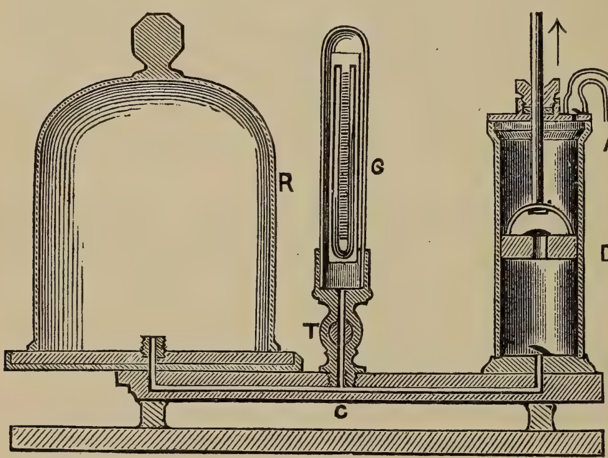


FIG. 89.

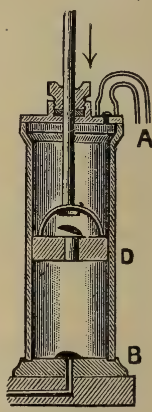


FIG. 90.

air escapes, while a part of the air in the receiver R flows through the valve B and occupies the vacuum formed below D. When the piston begins to descend, the valves A and B are closed (Fig. 90), and the air in DB flows up

through the valve in D. Thus at each double stroke of the piston a fraction of the air is removed from the receiver.

1. Of what use is the valve A?

2. What causes it to close when the piston descends?

3. What causes the valve in D to open and the valve B to shut when the piston descends?

8. Condenser.

It is frequently necessary to pump air into a receiver, as in filling the tubes of a bicycle. In this case the valves of the pump open downwards as shown in Fig. 91 instead of upwards as in the pump for withdrawing the air from the receiver.

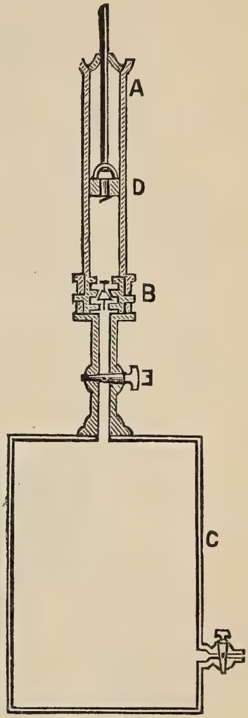


FIG. 91.

1. Explain the action of the valves B and D on (*a*) the down-stroke, (*b*) the up-stroke, and show how the density of the air in the vessel C is increased by the working of the pump.

2. Obtain a small bicycle pump, take it apart and study its construction and action.

9. Common Pump.

This pump is used for drawing water from a well or cistern.

The construction is shown in Fig. 92. A cylindrical barrel AB is joined to one end of a suction-pipe BC, the

other end of which is placed in the water to be drawn. A piston D, in which there is a valve opening upward, is

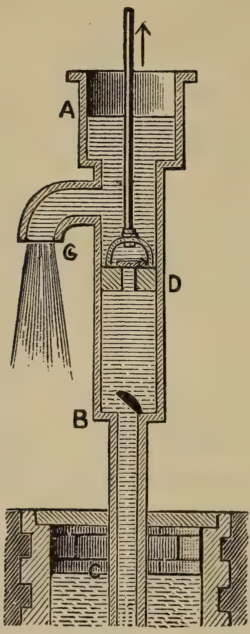


Fig. 92.

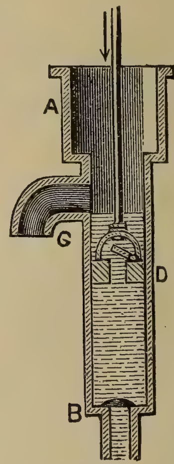


Fig. 93.

worked in the barrel by means of a piston-rod. At B there is a valve opening upward. At G a hole is made in the barrel and a spout is inserted.

Obtain a glass model[1] of a common pump and beginning with the pump empty, work the piston up and down observing the behaviour of the valves. Now lower the pump into a jar of water and observe (*a*) the action of the valves on (1) the up-stroke, Fig. 92, (2) the down-stroke, Fig. 93, (*b*) the action of the water within the suction-pipe and the barrel.

Explain the causes of the opening and closing of the valves in each of the above cases and also the upward movement of the water in the pump.

[1] For manual training exercise, see Appendix, page 327.

To answer the last question, review air pump, page 122, and experiments on pressure of the air, especially Experiment 7, page 110.

1. What is the greatest length which BC can have? Why?

2. How could a common pump be used to lift water from a very deep well?

3. Why does the water stand in the suction-pipe when the piston is not being worked?

4. A small hole is frequently made in the barrel of a pump to prevent the freezing of the water. If such a hole is bored, how high will the water stand in the pump when the piston is not being worked? Why?

5. The top of a well is covered and sealed air-tight. How will this affect the working of the pump (1) when the well is filled with water, (2) when it is partially filled? Explain.

10. Force Pump.

The force pump is used to raise water to a height or to drive it with force through a nozzle as, for example, for spraying or for use in extinguishing fire.

The construction is shown in Fig. 94. A cylindrical barrel AB is joined to one end of a suction-pipe BC, the other end of which is placed in the water to be drawn. A solid piston is worked in the barrel by a piston-rod. At D a hole is made in the barrel and a pipe E inserted, which opens into an air-tight vessel F, into which is inserted an outlet pipe G in the manner shown in the figure.

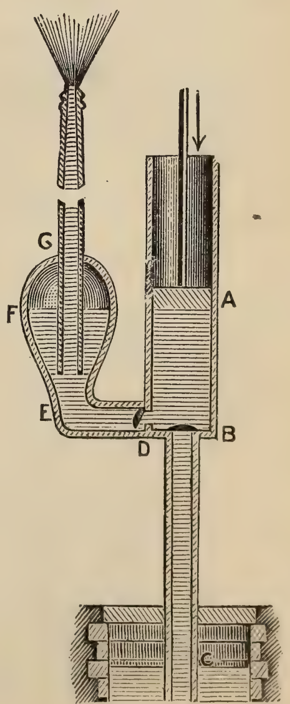


Fig. 94.

At B and D are valves opening outward.

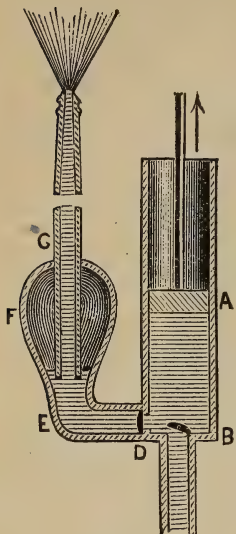


FIG. 95.

Procure a glass model[1] of a force pump, lower it into water and observe (*a*) the actions of the valves on (1) the down-stroke, Fig. 94, (2) the up-stroke, Fig. 95, (*b*) the action of the water in the suction-pipe, barrel and air chamber F.

1. Explain the opening of the valves in each of the above cases and also the movement within the pump.

2. If the end of the outlet pipe G is smaller than the pipe E, a continuous stream will tend to flow from it. Explain the action of the air chamber F in producing this effect.

11. Bramah's Press.

It is used for pressing goods into bales, extracting oils from seeds, lifting very heavy

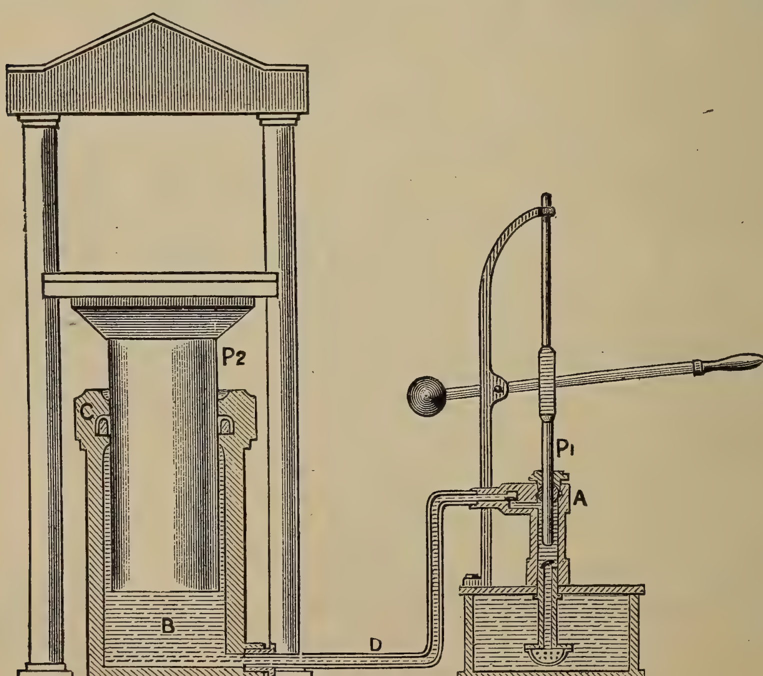


FIG. 96.

[1] For manual training exercise, see Appendix, page 327.

bodies, as for example, when ships are to be raised on blocks, and generally whenever great force is to be exerted.

Its construction is shown in Fig. 96.

It consists of a force pump A, the tube of which opens into a cylindrical vessel B with very strong, thick sides. In this cylinder there is a large piston or ram P_2 working water-tight in a collar C. A plate to hold the bodies to be pressed is attached to the upper end of the ram. Above this plate is a stationary one supported by the frame-work of the machine. The piston of the pump is worked by a lever.

12. Siphon.

Experiment 1.

Fill a glass tube of the form shown in Fig. 97 with water, stop each end, invert it and place one branch in a vessel filled with water, making sure the end of the other branch is below the surface of the water in the vessel. Unstop the ends of the tube.

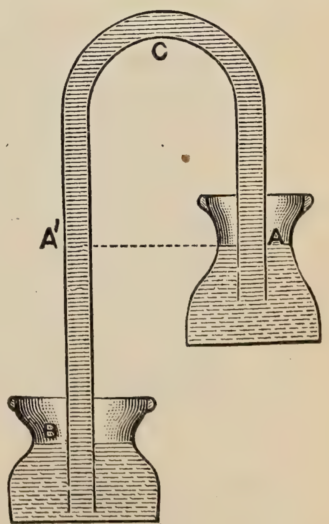


Fig. 97.

1. What takes place?
2. What is the cause?

To answer the last question consider,

(*a*) What is the pressure at A tending to move the water in the direction AC?

(See Experiment 7, page 110.)

(*b*) What is the pressure at B tending to move the water in the direction of BC?

(*c*) Which is the greater of these forces? Why?

A tube of this form used for transferring liquids from one vessel to another is called a **siphon**.

1. Upon what does the rapidity of flow in the siphon depend?

2. Will a siphon work in a vacuum? Explain.

3. Upon what does the limit of the height to which a liquid can be raised in a siphon depend?

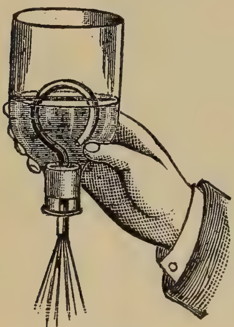


FIG. 98.

4. Will any change in the action of a siphon be coincident with a fall in the barometer? Explain.

5. Make a piece of apparatus similar to that shown in Fig. 98, by cutting the bottom off a bottle, bending a glass tube and inserting it into a perforated cork placed in the bottle. Let water from a tap run **slowly** into the bottle. What takes place? Explain.

6. Natural reservoirs are sometimes found in the earth, from which the water can run by natural siphons faster than it flows

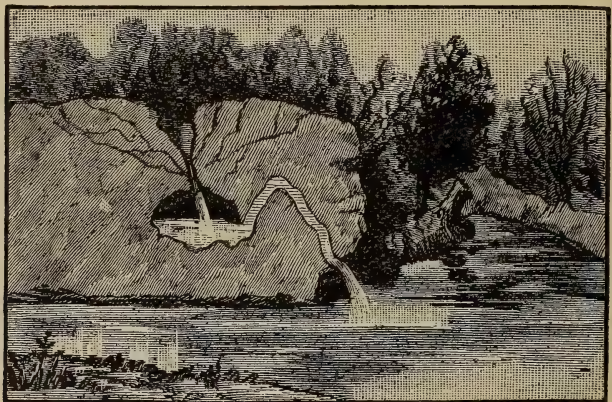


FIG. 99.

into them from above (Fig. 99). Explain why the discharge through such siphons is intermittent.

CHAPTER IX.

SOLUTION, DIFFUSION, OCCLUSION.

I.—Solution.

1. Solids in Liquids.

Experiment 1.

Place 15 grams of powdered potassic chlorate in a beaker containing 50 c.cm. of water at the temperature of the class-room. Stir the mixture for a few minutes.

Has the salt disappeared ?

If not, fold and cut a filter paper as shown in Fig. 100, place it in a funnel, pour the mixture into it, and collect the liquid passing through the filter paper (the filtrate) in another beaker.

FIG. 100.

1. Can you see any of the salt in the filtrate ?
2. Does this liquid contain any of the salt ?

To answer this question,

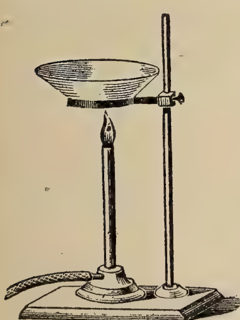


FIG. 101.

(1) Carefully remove the salt from the filter paper, and, when dry, weigh it.

1. Is all the salt present ?
2. If not, where must the remainder be ?

(2) Place the filtrate in an evaporating dish (a saucer will answer), and evaporate the water by gently heating the dish over a spirit lamp or Bunsen burner (Fig. 101).

1. What remains when the water has disappeared ?

2. How do you account for the fact that this substance was invisible in the water ? (See Art. 3, page 30.)

Experiment 2.

Repeat Experiment 1, placing the same quantity of the potassic chlorate in the same quantity of boiling water.

How does an increase in temperature affect the solution of this salt in water?

Experiment 3.

Place 15 grams of common salt in 50 c.cm. of water at the temperature of the class-room. Stir the mixture.

Which is the more soluble in cold water, potassic chlorate or common salt?

Experiment 4.

Place 5 grams of barium sulphate in 50 c.cm. of water, stir the mixture, filter, and evaporate the filtrate. Weigh the salt remaining on the filter paper.

Is barium sulphate soluble in water?

Experiment 5.

Place a crystal of iodine in a test-tube partly filled with water. Cork the tube and shake it.

Is the iodine soluble in water?

Uncork the tube, add two or three cubic centimetres of chloroform, cork it again and shake. Allow the tube to stand for a few seconds.

1. Describe what has taken place.

2. Account for (*a*) the colour of the lower liquid, (*b*) the relative positions of the liquids.

The solution of a solid in a liquid is dependent on—

1. **The Nature of the Solid and of the Solvent.**
2. **The Temperature.**

As a usual thing, the higher the temperature the greater is the quantity of the solid held in solution.

2. Mixtures and Compounds.

Experiment 6.

Pound up a little glass into a fine powder and mix it with iron filings. Look at the mixture through a magnifying glass.

1. Have the iron and the glass lost any of their characteristic properties by being mixed together?

2. Can the iron be separated from the mixture with a magnet? Try.

3. How does this mixture differ from the brine formed by adding salt to water? (Experiment 5, page 30).

When two substances are brought together and their properties remain altogether unchanged they are said to form **a mechanical mixture.** If when the substances are brought together any of the properties change, a re-action is said to take place and the product is called **a compound.**

The brine formed by dissolving salt in water is a compound because there is a change in some of the properties of the constituents when they are brought together, for example in volume. (See Experiment 5, page 30.)

Water itself is a compound because its constituents, oxygen and hydrogen gases, lose their characteristic properties when they combine (Experiment 2, page 305).

But the brine and water as compounds belong to different classes.

In brine the salt unites with the water in **variable proportions** to form a series of brines varying continuously in composition; while to form water the hydrogen combines with the oxygen in **fixed proportions,** namely,

one gram of hydrogen to eight grams of oxygen, and if more hydrogen is taken with this quantity of oxygen the excess of hydrogen remains unaltered.

Compounds of the first class are called **physical compounds**; those of the second class, **chemical compounds.**

3. Gases in Liquids.

Experiment 7.

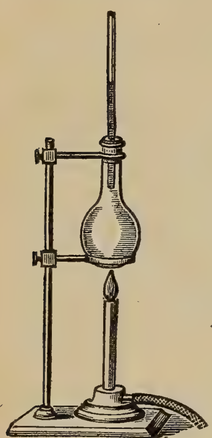


Fig. 102.

Fill a flask with water and insert a perforated rubber cork. See that there is no air under the cork. Push a glass tube through the cork so that the lower end is below the surface of the water in the flask (Fig. 102). Heat the water.

1. What collects at the surface of the water under the cork?

2. Where did it come from?

3. How does increasing the temperature affect the solubility of the gas in water?

Experiment 8.

Arrange apparatus as in Fig. 103. Into the flask B pour 10 c.cm. of strong liquor ammoniæ. Open the stop-cock, fit the cork into B, but leave flask A uncorked as shown. Gently heat B. When A is filled with ammonia gas, which will be known by the strong odor observed when it escapes into the room, remove the cork from B, shut the stop-cock, pour about a tablespoonful of water into A, and place the cork in it at once. Dip the free end of the tube into water (Fig. 104) and open the stop-cock.

1. What takes place? Give the reason.

2. What becomes of the gas that was in the flask A?

3. Which is the more soluble in water, ammonia gas or air? How do you know?

4. Are the solutions formed above mechanical mixtures or compounds? If compounds, to which class do they belong?

Experiment 9.

Partly fill a beaker with water, place it under the receiver of an air pump and exhaust the air from the receiver. ?

1. What do you observe to collect on the sides of the beaker?

2. Is the pressure to which the water is subjected increased or decreased by removing the air from the receiver?

3. What is the relation between pressure and the amount of gas held in solution by a liquid?

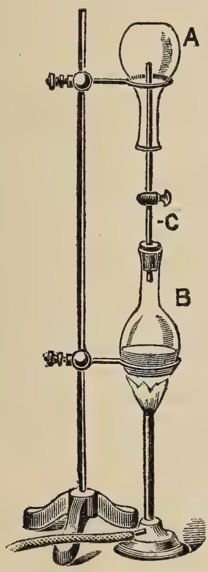


FIG. 103.

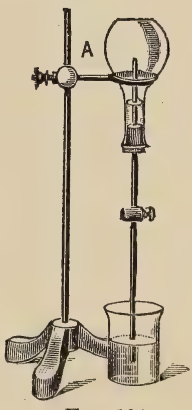


FIG. 104.

The solution of a gas in a liquid is dependent on—

1. **The Nature of the Gas and of the Solvent.**

2. **The Temperature; the higher the temperature the less the quantity of gas held in solution.**

3. **The Pressure; the higher the pressure the greater the quantity of gas held in solution.**

II.—Diffusion.

4. Free Diffusion of Liquids.

Experiment 1.

Fill a glass jar of the form shown in Fig. 105 about two-thirds full of water, and by means of a thistle-tube introduce beneath the mass of the water one-third as much of a concentrated solution of copper sulphate. Allow the jar to stand undisturbed for a few days. Observe it from time to time.

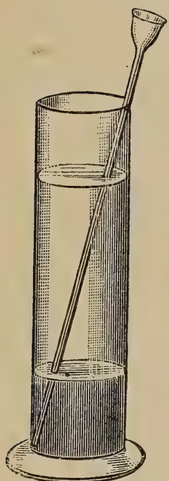


FIG. 105.

Experiment 2.

Partially fill a test-tube with a solution of blue litmus, and pour into a thistle-tube which reaches the **bottom** of the test-tube a few drops of sulphuric acid. Let the tube stand for a few days and observe from time to time the position of the upper surface of the lower liquid.

(To show the action of sulphuric acid when mixed with the solution of litmus, add a drop of the acid to some of the solution in another tube and stir the mixture.)

1. Is the bounding surface between the liquids in the jar (Experiment 1), and in the tube (Experiment 2), sharply defined at first?

2. Describe what you observed to take place in each case when the tubes were allowed to stand.

This intermingling of liquids in contact with one another is known as **free diffusion.** It is probably due to the constant movement of the molecules from place to place throughout the mass of the fluid.

Will any liquid diffuse through any other? Try coal oil and water, water and mercury.

Substances differ widely in their rates of diffusion. Solids which when in solution diffuse rapidly, are usually crystalline in structure, and hence are known as **crystalloids**; while those which diffuse slowly are usually amorphous in structure, and are known as **colloids.** To the latter class belong such bodies as starch, gelatine, albumen, and gummy substances generally.

5. Diffusion of Liquids Through a Membrane—Osmose.

Experiment 3.

Tie a piece of moistened parchment paper or other animal membrane (a piece of bladder answers well) over the funnel of a thistle-tube. Fill the funnel and part of the tube with a concentrated solution of copper sulphate, and support it (as shown in Fig. 106) in a vessel of water, so that the water on the outside may reach the same level as the solution on the inside of the tube. Set it aside for two or three hours, and observe from time to time the height of the liquid in the tube.

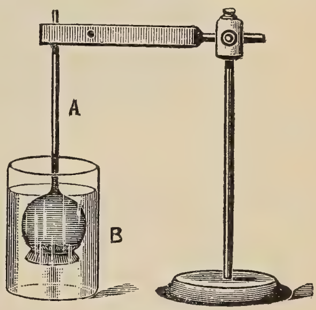


FIG. 106.

1. What change has taken place in the height of the solution in the tube?

2. What change has taken place in the water?

3. How do you know (*a*) that water has passed into the tube, (*b*) that the copper sulphate solution has passed out of it?

4. Which is the greater, the quantity of the water passing into the tube or the quantity of the solution passing out of it? How do you know?

This intermingling of liquids by forcing their way through membranes is known as **osmose.**

6. Dialysis.

The unequal diffusibility of different substances through membranes is taken advantage of by the chemist for the purpose of separating bodies that are mixed. The process is called **dialysis.** The dialyser is a wooden or hard rubber hoop, over one end of which is stretched (as shown in Fig. 107), while wet, a piece of parchment paper. The

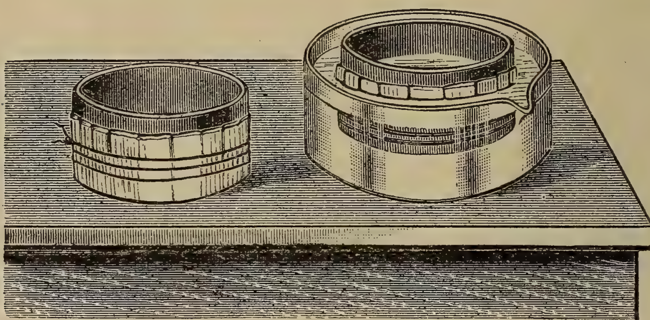


FIG. 107.

mixed solution to be dialysed is placed in the vessel thus formed, and this vessel is floated on pure water contained in another vessel. In a few days the liquids are more or less completely separated, the greater part of the more diffusible one having passed out into the water.

Experiment 4.

Separate a mixed solution of common salt and starch.

Make a dialyser by cutting off a large bottle three or four inches below the neck and making a bottom by tying parchment paper over the open end. Place in this vessel the mixed solution, and suspend it (as shown in Fig. 108) in a vessel containing water for a few days.

1. Is there any salt in the water in the vessel?

To answer this question, add to a little of the water a few drops of silver nitrate solution. If salt is present a white precipitate will be formed.

2. Is there any of the starch in the water in the vessel?

To answer this question, add to a little of the water a crystal of iodine. If starch is present, the water will be turned a deep blue colour.

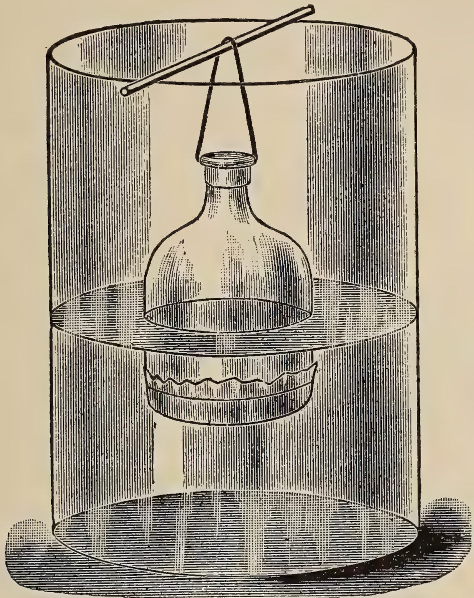


FIG. 108.

7. Free Diffusion of Gases.

Experiment 5.

Pour a little liquor ammoniæ into an evaporating dish, and warm the dish over a spirit lamp or Bunsen burner.

What evidence have you that ammonia gas has mingled with the air?

This experiment is illustrative of the free diffusion of gases. Any gas will diffuse readily through any other, probably because the molecules of one gas, in their free motion, pass easily into the spaces between the molecules of the other gas.

8. Diffusion of Gases Through a Porous Partition.

Experiment 6.

Arrange apparatus as in Fig. 109. A is a porous battery-cell, B a glass tube fitted into a perforated rubber cork inserted into the cell, C is a bent tube containing water (a calcium chloride or thistle-tube answers well for this purpose). The large branch of the tube is connected with B by means of a perforated cork, and the end of the small branch is drawn out into a jet. Place on the outside of the porous cell a glass jar D, and fill it with hydrogen gas. This may be prepared by pouring water acidulated with about one-tenth its volume of sulphuric acid over some zinc clippings placed in a flask E. The hydrogen will pass up through the tube F and fill the jar D. Since the air is denser than the hydrogen, its buoyancy will cause the hydrogen to remain in the jar.

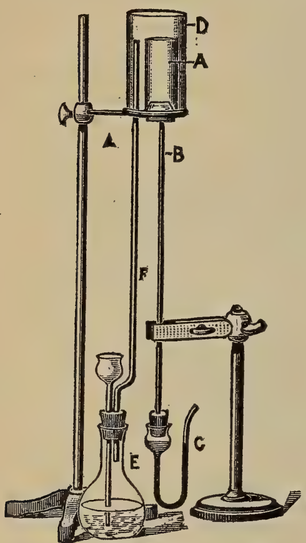


FIG. 109.

1. What evidence have you that additional pressure is being exerted on the surface of the water in the large branch of C ?

This increased pressure arises from the fact that the hydrogen passes more rapidly through the pores in the porous cell than the denser air passes out of it.

2. Remove the bottle containing the hydrogen. What change takes place in the water levels in the tube C ? Why ?

Experiment 7.

Arrange apparatus as shown in Fig. 110. A is a porous battery-cell, B a bent glass tube fitted into a perforated

rubber cork inserted into the cell. The lower end of B dips into water in a vessel C. Fill a wide-mouthed jar D with carbon dioxide, a gas which is denser than air. This may be done by placing a teaspoonful of baking soda or washing soda in the bottom of the jar and covering it with acidulated water. Place the porous cell in the jar, keeping it above the liquid, as shown in the figure. Observe the water in the tube B.

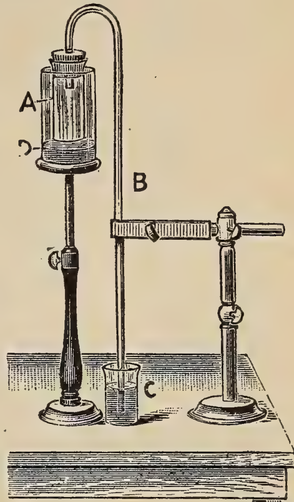


FIG. 110.

1. What takes place?

2. What should take place if the jar containing the carbon dioxide were removed? Try.

3. What change now takes place in the water levels? Explain.

9. Diffusion of Gases Through a Membrane.

Experiment 8.

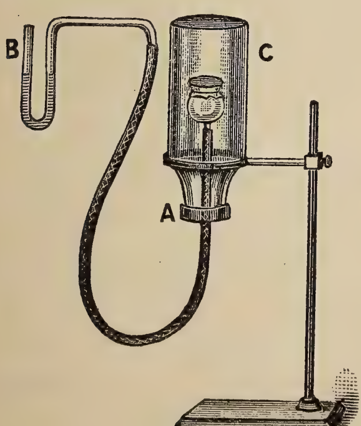


FIG. 111.

Repeat Experiment 6 above, placing in the hydrogen the thistle-tube used in Experiment 3, page 135, instead of the porous cell. Connect the thistle-tube with a pressure-gauge (Fig. 111).

What change takes place in the water levels in the gauge? Explain.

Remove the hydrogen jar. What results? Why?

Experiment 9.

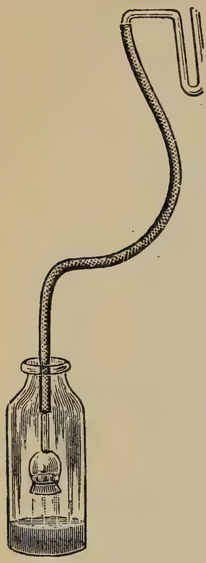


Fig. 112.

Repeat Experiment 8, using carbon dioxide gas instead of hydrogen (Fig. 112).

What is the cause of the differences in pressure indicated by the gauge?

The above experiments prove that the rapidity of diffusion of a gas depends on its density. The greater the density of a gas the less is its rate of diffusion. Exact experiments conducted by Loschmidt, who has investigated the phenomena of free diffusion, and by Graham, who has investigated the phenomena of diffusion through porous septa, have established the following law.

10. Law of Diffusion of Gases.

The relative rates of diffusion of gases are inversely proportional to the square roots of their densities.

For example, the densities of oxygen and hydrogen are in the ratio, 16 : 1, and their rates of diffusion are in the ratio, 1 : 4, that is, $\sqrt{1} : \sqrt{16}$.

The diffusion of gases is of great importance in the economy of nature. If gases would float on one another, as oil on water, or water on mercury, the present forms of life could not exist. The requisite proportion of nitrogen to oxygen in the air would not be maintained, and the noxious gases exhaled by animals and generated by the decomposition of organic matter would collect in dangerous proportions at the earth's surface.

III.—Occlusion.

Experiment 1.

Heat a piece of charcoal to redness in a flame, allow it to cool, and introduce it into a tube, filled with ammonia gas as in Experiment 8, page 132. Place the tube in a vertical position with its open end in mercury (Fig. 113).

What change takes place in the volume of the gas in the tube?

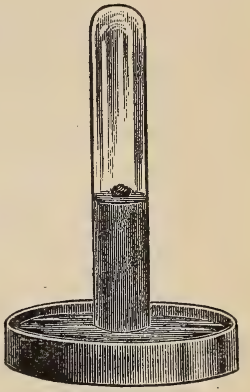


FIG. 113.

For various reasons it is believed that the gas absorbed by the charcoal is condensed on its surface. All solids appear to possess to a greater or less extent this power of condensing gases on their surfaces.

The amount of the condensed gases is dependent on—

11. The Area of the Surface of the Solid.

A small piece of charcoal, on account of its porous condition, presents a very large surface to a gas in which it is placed.

12. The Nature of the Solid and of the Gas.

Charcoal condenses about twice as much ammonia as it does carbon dioxide on the same surface.

Certain metals, especially platinum and palladium, possess this power in a high degree.

13. The Temperature.

The absorption of a gas by a metal has received the name of **occlusion.**

The efficiency of charcoal as a deodorant and disinfectant is probably due to the action of the oxygen condensed in its pores upon the noxious gases.

CHAPTER X.

SPECIFIC GRAVITY.

1. Relation Between Specific Gravity and Density.

Repeat the determinations 5, 6 and 7, page 71.

In determining the densities of the bodies named relative to the density of water the student has been determining what is known as the **specific gravities of the bodies.**

The **specific gravity,** or **relative density,** of a substance is the ratio of its density to that of some standard, or, what amounts to the same thing, the **ratio of the mass of any volume of the substance to the mass of an equal volume of the standard substance.** For solids and liquids the standard is pure water at 4°C.

We have seen that the density of a body is the mass of a unit volume of it. In the C.G.S. system of units, since the cubic centimetre is the unit of volume and the gram the unit of mass, and one cubic centimetre of water has a mass of one gram, the number expressing the density of a body will also indicate its specific gravity. For example, the specific gravity of gold is 19·36; that is, a piece of gold weighs 19·36 times as much as the same volume of water; but the density of water is one gram per cubic centimetre, therefore the density of gold is 19·36 grams per cubic centimetre.

While the numbers are the same it should be carefully noted that the measure of the density is the **number of units of mass** (grams) in a unit of volume

(cubic centimetre), and the specific gravity of a body is the **number of times** the mass of any volume of the body contains the mass of the same volume of water.

Or, the specific gravity of a body

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water}}.$$

2. Determination of Specific Gravity of Bodies.

Since the specific gravity of a body

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water}},$$

in finding the specific gravity of a body, two quantities have to be determined.

1. The **Mass** of the body. This can always be found by weighing.

2. The **Mass of an Equal Volume of Water.**

If the substance whose specific gravity is to be determined is a liquid, its volume can be determined by measuring it in a measuring vessel, and the mass of an equal volume of water computed.

How is the mass of this water computed when its volume is determined?

If the body whose specific gravity is to be determined is a solid, the mass of an equal volume of water is usually determined in one of two ways.

(*a*) By determining first the volume of the water displaced by the body in a graduated vessel as in Experiment 6, page 27, and then computing its mass.

(*b*) By applying Archimedes' Principle.

If a body weighs W in air and W_1 in water, what is the measure of the buoyant force of the water?

What is the measure of the buoyant force of any liquid on any solid? (See Art. 17, page 105).

What, therefore, is the measure of the mass of the water equal in volume to solid ?

We shall consider some of the more common cases and methods in the following sections.

3. To Find the Specific Gravity of a Solid Heavier than Water.

Method 1.

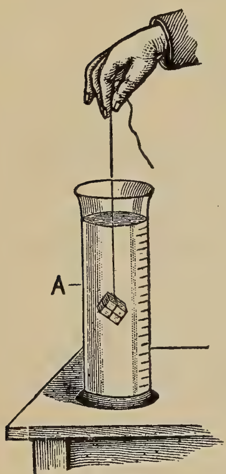


FIG. 114.

Experiment 1.

Weigh a piece of lead.

Mass (W)= gm. ?

Tie a thread to it and sink it in a graduated tube partially filled with water (Fig. 114). Observe the volume of the water displaced by it.

Volume (V)= c.cm. ?

But the mass of 1 c.cm. of water is 1 gram.

Therefore V grams=mass of water equal in volume to the wood.

$$\text{But the specific gravity of lead} = \frac{\text{its mass}}{\text{mass of equal volume of water.}}$$

$$= \frac{W}{V} = \quad ?$$

If the solid is soluble in water another liquid in which it is not soluble may be used in the graduated tube.

Method 2.

Experiment 2.

Weigh an iron nail in air.

Mass (W)= ?

Tie a thread to it, suspend it from the scale-pan of a balance and weigh it when surrounded with water (Fig. 115).

$$\text{Mass } (W_1) = \quad ?$$

Therefore $W - W_1$ = the loss in weight in water.
= the buoyancy of the water.
= the mass of water equal in volume to the nail (Art. 17, page 105).

But the specific gravity of a body

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water.}}$$

Therefore the specific gravity of the nail

$$= \frac{\text{its mass}}{\text{loss of weight in water,}}$$

$$= \frac{W}{W - W_1} = \quad ?$$

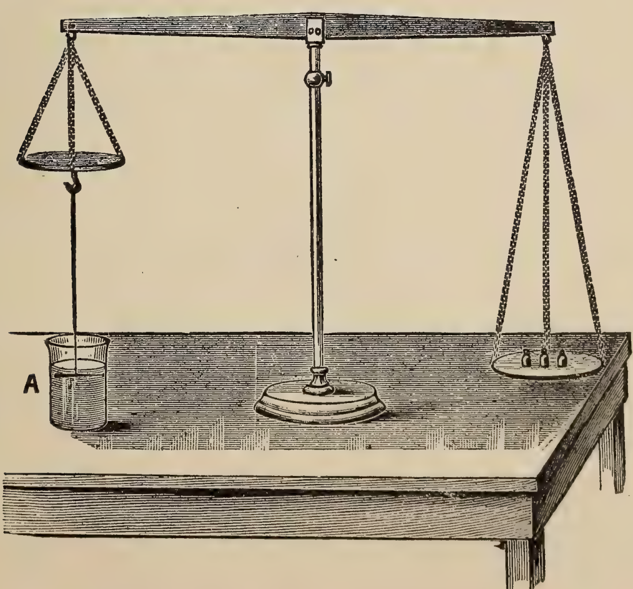


FIG. 115.

Experiment 3.

Find in the same way the specific gravities of pieces of glass, lead, rock, etc.

If the solid is soluble in water, its specific gravity may be obtained by finding, as above, the ratio of its mass to that of an equal volume of some liquid in which it is not soluble, and then multiplying the result by the specific gravity of this liquid.

4. To Find the Specific Gravity of a Solid lighter than Water.

Method 1.

Experiment 4.

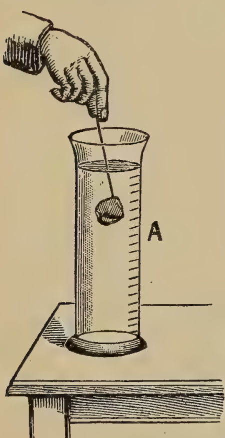


Fig. 116.

Weigh a piece of wood.

Mass (W)= gm. ?

By means of a needle, or a piece of fine wire, sink it into a graduated tube partially filled with water (Fig. 116). Observe the volume of the water displaced by it.

Volume (V)= c.cm. ?

But the mass of 1 c.cm. of water is 1 gram. Therefore V gm. = mass of water equal in volume to the wood.

Specific gravity of the wood

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water,}}$$

$$= \frac{W}{V} = \quad ?$$

If the solid is soluble in water, another liquid in which it is not soluble may be used in the graduated tube.

Method 2.

Experiment 5.

Weigh a piece of wood.

Mass (W)= ?

Tie a piece of lead to the wood and weigh the two together when surrounded with water.

$$\text{Weight } (W_1) = \quad ?$$

Now weigh the lead alone when surrounded with water.

$$\text{Weight } (W_2) = \quad ?$$

Then $W_1 - W_2$ = the weight of the wood alone in water, and

$$W - (W_1 - W_2) \text{ or } W - W_1 + W_2$$

= the loss of weight in the wood when weighed in water.

$$\text{Specific gravity of the wood} = \frac{\text{its mass}}{\text{loss of weight in water.}}$$

$$= \frac{W}{W - W_1 + W_2} = \quad ?$$

Experiment 6.

Find the specific gravities of pieces of oak, pine, and cork, etc., by methods 1 and 2.

5. To Find the Specific Gravity of a Powder.

Experiment 7.

Find the specific gravity of a sample of sand. Weigh the sand.

$$\text{Mass } (W) = \quad ?$$

Counterpoise on a balance a specific gravity bottle, that is, a bottle which, when filled to a certain mark, contains a known mass of water, say m grams (Fig. 117).

Introduce the sand into the bottle, and fill the remaining space in the bottle with water. Weigh the water and sand in the bottle.

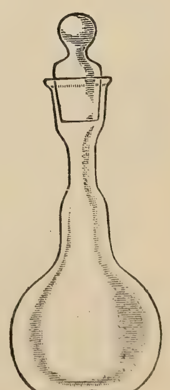


FIG. 117.

$$\text{Mass } (W_1) = \quad ?$$

Let x = the mass of water displaced by the sand.

Then $m-x$ = mass of water in the bottle.

But W_1 = mass of water + mass of sand,

or $W_1 = m - x + W.$

Therefore $x = W + m - W_1$

= mass of water equal in volume to the sand.

The specific gravity of the sand

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water.}}$$

$$= \frac{W}{W + m - W_1} = \quad ?$$

6. To Find the Specific Gravity of a Liquid by the Specific Gravity Bottle.

FIG. 118.

Specific gravity bottles are of various forms. Figure 118 shows one of the most common. It is a small glass bottle, with a perforated glass stopper, made to contain a definite mass of water when filled and the stopper inserted. Figure 117 shows another form of the bottle.

Instead of a bottle, a pipette with a very fine bore, graduated to contain a definite volume, say 10 c.cm., may be used for rapid determinations of specific gravities. It may be supported on the scale-pan of a balance by a wire support (Fig. 119).

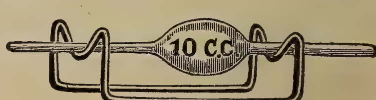


FIG. 119.

Experiment 8.

Counterpoise on a balance a specific gravity bottle which is made to contain a definite mass (m) of water. Fill it with alcohol and weigh the alcohol.

$$\text{Mass (W)} = \quad ?$$

The volume of the alcohol is the same as the volume of the water which fills the bottle.

Specific gravity of alcohol

$$= \frac{\text{its mass}}{\text{mass of an equal volume of water.}}$$

$$= \frac{W}{m} = \quad ?$$

Experiment 9.

Find in the same way the specific gravities of samples of vinegar and coal oil.

7. To Find the Specific Gravity of a Liquid by the Common Hydrometer.

Experiment 10.

Make of wood a rectangular rod[1] 1 sq. cm. in section and 20 cm. long. Mark off on one of its long faces a centimetre scale (Fig. 120). Bore into one end a hole to the depth of several

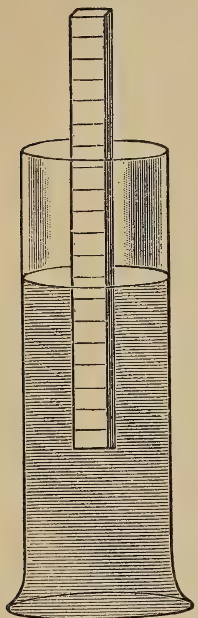
FIG. 120.

centimetres. Fill the whole with a sufficient weight of shot to cause the rod to float vertically in water. Close the hole with plaster of Paris or cement. Place the rod, with the weighted end down, in a vessel containing water (Fig. 121).

[1] For manual training exercise, see Appendix, page 328.

1. How deep does it sink in water?

2. How many cubic centimetres of water does it displace?



3. How many grams of water does it displace?

4. What is the mass of the rod? (Page 105.)

Now place the rod in the same position in alcohol.

1. How many cubic centimetres of alcohol does it displace?

2. How does the mass of the rod compare with the mass of the alcohol displaced?

3. What then must be the mass of the number of cubic centimetres of alcohol displaced by the rod?

4. What, therefore, is the mass of one cubic centimetre of alcohol?

FIG. 121.

5. What is the specific gravity of the alcohol?

From the above reasoning it is seen that **when the same body floats in different liquids the volumes of the liquids displaced by it are inversely proportional to their specific gravities.**

Instead of a rod constructed as described, an instrument called a hydrometer is generally employed to take advantage of this principle in determining the specific gravities of liquids.

The **common hydrometer** consists of a hollow sphere or cylinder A, to which is attached on one side a slender graduated stem B, and on the other side a small sphere C, loaded to cause the instrument to float vertically in a

liquid (Fig. 122). The weight and volume are so adjusted that the instrument sinks to the division mark at the lower end of the stem in the most dense liquid to be investigated, and to the division mark at the upper end of the stem in the least dense liquid. The scale on the stem indicates the specific gravities of liquids between these limits.

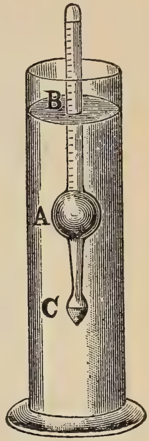


FIG. 122.

As the range of an instrument of this class is necessarily limited, special instruments are constructed for special liquids. For example, one instrument is used for determining the specific gravities of milks, another for petroleum oils, another for alcohols, etc.

1. If a body when floating in water displaces 10 c.cm., what is the density of a liquid in which when floating it displaces 15 c.cm.?

2. If the specific gravity of pure milk is 1·086, what is the specific gravity of a mixture containing 500 c.cm. of pure milk and 100 c.cm. of water?

3. A body weighing 10 grams has attached to it a piece of lead, and the two together when submerged displace 50 c.cm. of water. The lead alone displaces 10 c.cm. What is the density of the body?

4. If the specific gravity of gold is 19·36 and that of silver is 10·5, what is the specific gravity of a lump made up of 38·72 grams of gold and 31·5 grams of silver?

5. A hydrometer floats with $\frac{3}{4}$ of its volume submerged when floating in water and $\frac{2}{3}$ of its volume submerged when floating in another liquid. What is the density of this liquid?

6. A body which weighs 10 grams in air has a sinker attached to it and the two together weigh 20 grams in water. The sinker alone weighs 30 grams in water. What is the density of the body?

8. To Find the Specific Gravity of a Liquid by Balancing a Column of it by a Column of Water.

Experiment 11.

Find the specific gravity of a solution of common salt.

Take two glass tubes, *a* and *b*, each about 75 cm. in length and of the same size, connect them with a T tube, to which is attached a piece of rubber tubing (Fig. 123). Place the lower end of one tube in water and that of the other in the salt solution. Support the tubes in a vertical position. By suction upon the rubber tube draw the liquids part way up into the glass tubes. Close the rubber tube with a clamp.

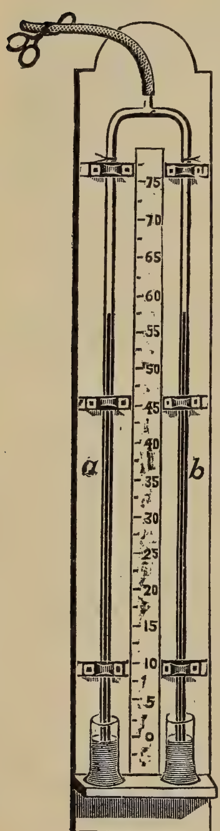


Fig. 123.

Observe the heights of the liquids in the tubes above the surfaces of the liquids in the vessels.

1. What force supports the weight of the liquid in each tube?

2. How does the mass of the water in one tube compare with the mass of the salt solution in the other?

3. How does the volume of the water in one tube compare with the volume of the salt solution in the other?

4. What is the specific gravity of the salt solution?

5. Is it necessary that the tubes *a* and *b* should be of the same size?

9. To Find the Specific Gravity of a Liquid by Weighing a Solid in the Liquid and in Water.

Experiment 12.

Find the specific gravity of glycerin.

Weigh a piece of iron.

$$\text{Mass } (W) = \quad ?$$

Weigh the iron immersed in water.

$$\text{Weight } (W_1) = \quad ?$$

Weigh the iron immersed in glycerin.

$$\text{Weight } (W_2) = \quad ?$$

Then $W - W_1$ = mass of water displaced by iron

and $W - W_2$ = mass of glycerin displaced by iron.

But the volume of the water displaced by the iron equals the volume of the displaced glycerin.

$$\text{Specific gravity of glycerin} = \frac{W - W_2}{W - W_1} = \quad ?$$

Experiment 13.

Make a solution of alcohol and water such that beeswax will just float in it totally immersed. Find the specific gravity of the solution and from it determine the specific gravity of the wax.

Experiment 14.

Find the specific gravity of a sample of milk. Mix this milk with water in the ratio of two volumes of milk to one of water. Find the specific gravity of the mixture. Test your result by theory.

10. To Find the Specific Gravity of a Gas.

The specific gravities of gases may be determined by means of a large, light specific gravity bottle fitted with a stop-cock which can be screwed to an air pump. The air is exhausted

from the flask, and the flask counterpoised on a balance. It is then filled with the gas whose specific gravity is to be determined, at a set temperature and pressure, and the gas is weighed. This weight is compared with the weight of a bottleful of the standard with which the gas is to be compared. This standard is frequently air at 0° C. and 76 cm. barometric pressure instead of water.

Why must the temperature and the pressure be noted in finding the specific gravity of a gas ?

CHAPTER XI.

FORMS OF ENERGY—TRANSMUTATION OF ENERGY.

In Chapters V–X we have been discussing topics more especially related to matter. We shall now return to the consideration of energy, its forms and transmutations.

1. Forms of Energy.

A body may possess energy in consequence of bodily onward motion, of which we have considered several examples. But, as has already been indicated, this is not the only condition under which a body may possess energy.

Experiment 1.

Strike a tuning-fork on the table and immediately place the prongs so as just to touch the surface of some water (Fig. 124).

FIG. 124.

1. What evidence have you that the fork possesses energy?

2. Is there any visible motion of the fork in this case?

3. What is the nature of this motion?

4. Mention other examples of similar motion?

5. When the tuning-fork is struck, what sensation is experienced by all within a moderate distance from the fork?

6. Upon what part of the body is work done to produce this sensation?

7. As the fork is not in contact with your ear, how can it do work on your ear?

8. What is there between the fork and the drum of your ear?

9. If this medium receives energy from the fork and transfers it to your ear, what is the condition of this medium while it possesses the energy?

Experiment 2.

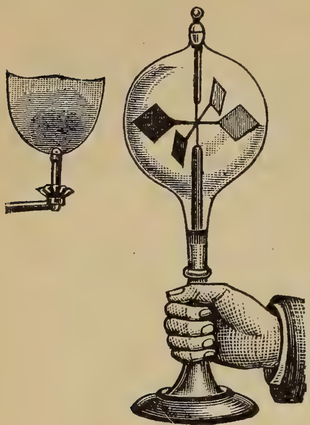


Fig. 125.

Place a radiometer near a hot body such as the flame of a gas burner or a red-hot metal ball (Fig. 125).

1. What evidence have you that work is being done on the radiometer?

2. What is the result when the radiometer is exposed to the sunlight?

3. Is the sun in a position to do work **directly** on the radiometer?

4. What must therefore possess the energy after it leaves the sun and before it is received by the radiometer?

We are thus led to see that there are various forms of energy, all doubtless possessed by matter of some kind having some mode of motion.

1. **Energy of bodily onward motion.**

2. **Energy of bodily vibration.**

3. **Energy of molecular vibration, or heat.** (See page 49.)

4. **Radiant energy,** or the energy possessed by the intangible medium called luminiferous ether, which we suppose to fill all space.

5. **The mysterious forms of energy which produce gravitation, chemical affinity, magnetic attraction, magnetic repulsion, etc.,** and which may be forms of radiant energy. (See page 50).

6. **The energy of the electric current,** which is well exhibited in the electric motor. This also is probably a form of radiant energy.

2. Transmutation of Energy.

When energy is changed, as it may be, from one form to another, we say that energy has been transformed or transmuted.

We shall consider more fully some of these transmutations in connection with the discussion of the sources of each of the forms of energy we are about to study. The source of any one form of energy is always some other form.

3. Conservation of Energy.

Careful experiments, which are quite beyond the limits of an elementary work, have led to the following general conclusion, which is now universally accepted.

In all transformations and transferences of energy no energy is created or destroyed. In short, **the total amount of the energy of the universe is a constant quantity.**

This general conclusion is known as the **law of conservation of energy.**

In the following chapters we shall study more in detail some of the forms of energy named above, beginning with sound or the energy of bodily vibration, and then taking in order, heat, light, and the energy of the electric current.

CHAPTER XII.

ORIGIN AND NATURE OF SOUND.

I.—Vibratory Motion.

1. Vibration.

Experiment 1.

Suspend a weight by means of a wire or cord. Draw the weight aside, let it go and observe its motion. (Fig. 126.)

Fig. 126.

1. Describe the changes in velocity which take place.

2. Is the number of times which it moves to-and-fro the same during equal intervals of time?

When the motion of a body, like that of the suspended weight, is alternate in direction, it is said to be **oscillatory**, or **vibratory.**

The time required to perform a complete vibration is called the **period of vibration.**

The number indicating the number of vibrations in a unit of time is called the **vibration-number**, or **vibration-frequency.**

The extent of the excursion of the vibrating body on either side of the middle point, or point of rest, is called the **amplitude** of the vibration.

What change takes place in the amplitude of the vibration, as the weight (Exp. 1) moves to-and-fro?

2. Direction of Vibration.

Experiment 2.

Fasten a steel spring in a small vice, as shown in Fig. 127, draw it aside and let it go. Observe its motion.

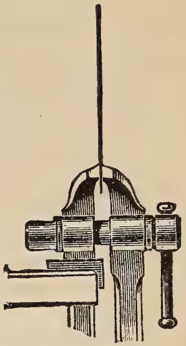


FIG. 127.

When the direction of the motion of the vibrating body is at right angles to its length, the vibrations are said to be **transverse.**

Experiment 3.

Attach a weight to the end of a suspended coil spring, as shown in Fig. 40, pull it down a little way and let it go.

Describe its motion.

When, as in this case, the body vibrates lengthwise, the vibration is said to be **longitudinal.**

Experiment 4.

Attach a pointer to a weight, and suspend it, by means of a wire, over a graduated circle drawn on paper, as shown in Fig. 51. Twist it around and let it go.

Describe the motion of the weight.

When a body vibrates by twisting in alternate directions, the vibration is said to be **torsional.**

1. What is the direction of the vibration in each of the following cases?

(1) When a pendulum vibrates.

(2) When a violin-string is set vibrating.

(3) When the body of a carriage moves up and down on account of the elasticity of the springs.

(4) When the hair-spring of a watch vibrates.

(5) When a flag waves in the wind.

2. Give additional examples of bodies vibrating :—

(1) Transversely.

(2) Longitudinally.

(3) Torsionally.

II.—Sound Caused by Vibration.

3. Vibration of Strings.

Experiment 1.

Stretch a string tightly between two pegs (Fig. 128). Pluck it.

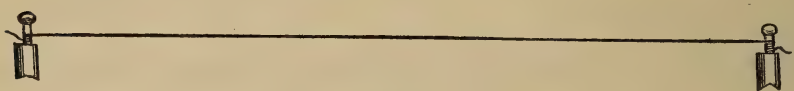


Fig. 128.

Is the sound produced accompanied by vibrations of the string? How do you know?

4. Vibration of Rods.

Experiment 2.

Cut a ball about the size of a pea from a cork, dip it in some spirit varnish, and when dry attach to it a piece of fine silk fibre. Place a short brass rod in a vice as shown in Fig. 129. Draw a violin-bow across the upper end of the rod, and, holding the free end of the silk fibre in the hand, bring the cork ball so that it will just touch the upper end of the rod when it is giving forth a sound.

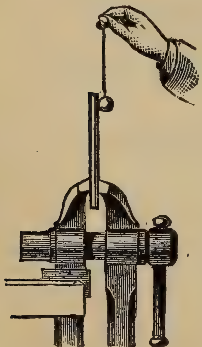


Fig. 129.

What takes place? Explain the reason.

Experiment 3.

Fasten the middle of a brass rod about two feet long in a vice as shown in Fig. 130. Suspend by two fibres the cork ball used in the last experiment, and bring it so that it will just touch the free end of the rod. Rub the rod lengthwise with a piece of leather upon which powdered resin has been sprinkled.

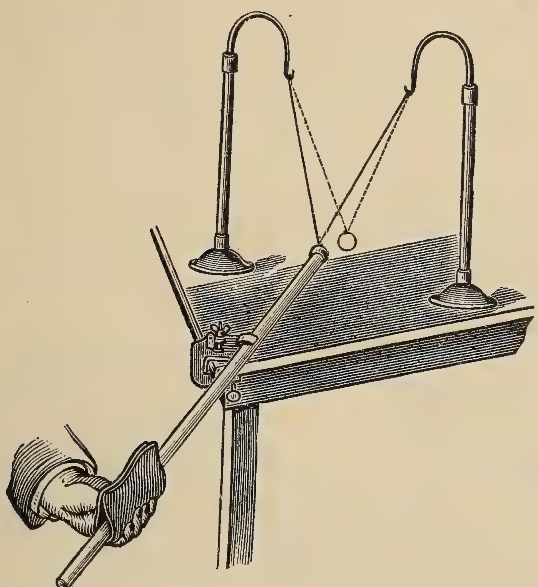


FIG 130.

1. What evidence have you that the rod is vibrating?

2. How does its manner of vibration differ from that of the rod in the last experiment?

5. Vibration of a Tuning-Fork.

Experiment 4.

Place a match on the ring of a retort stand (Fig. 131). Strike the end of a prong of a tuning-fork a sharp blow on a piece of rubber or thick paper folded over the edge of the table. Now touch one of the prongs of the fork to the middle of the match.

What takes place? Explain the reason.

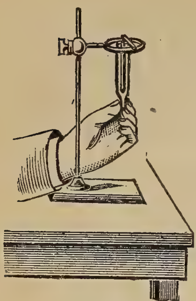


FIG. 131.

Strike the fork again and immediately place the prongs so as just to touch the surface of some water. (Fig. 124.)

1. What evidence have you that the fork is in motion?

2. What is the nature of the motion of the fork?

To answer the last question perform the following two experiments.

Experiment 5.

Arrange apparatus as shown in Fig. 132. The block is made by nailing pieces of board together. The tuning-fork is so

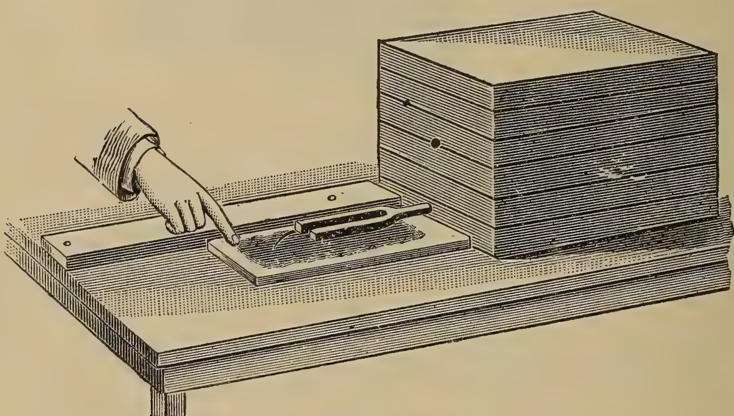


FIG. 132.

placed that the point of a fine style attached to the lower side of one of the prongs just touches the upper smoked surface of a piece of glass, placed on the table below it. A straight strip of board is tacked to the table to serve as a guide for the glass. Set the fork in motion by drawing a violin-bow across one of the prongs, and slide the glass quickly along the guide, moving it at a uniform rate.

1. Hold the glass up to the light, and describe the form of the tracing.

2. How was the prong of the fork moving?

Experiment 6.

Insert the fork into the centre of one of the ends of the block, and place it in an inclined position, as shown in Fig. 133. Set the fork in motion as before, and, holding the end of the fibre in your hand, bring the ball used in Experiment 2 so that it will touch a prong of the fork just above the crotch. Slowly raise the ball, keeping it alongside the fork.

1. Describe the motion of the ball.

2. When is its displacement by the fork the greatest? When the least?

3. How does the prong of the fork move?

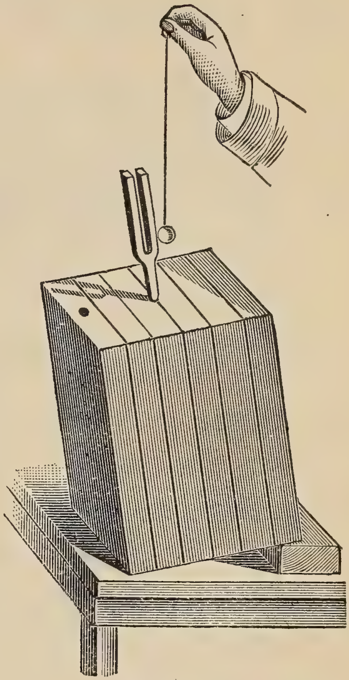


FIG. 133.

FIG. 134.

Withdraw the fork from the block, strike one of the prongs a sharp blow, and bring the ball against the end of the handle.

1. What takes place?

2. How does the handle of the fork vibrate?

These experiments show that the prongs of the fork oscillate about stationary points PP (Fig. 134) near the crotch, and that the handle vibrates longitudinally.

Points of rest in a vibrating body are called **nodal points** or **nodes.**

6. Vibration of Plates.

Experiment 7.

Take a brass plate about 3 millimetres in thickness and about 20 or 25 centimetres square, and hold it in a horizontal position by a suitable clamp at the centre (Fig, 135). Scatter fine sand over the plate, and touch the middle point of one of the edges with the finger and draw a violin-bow across the edge near one of corners, causing the plate to give a clear strong sound. Observe the movement of the sand.

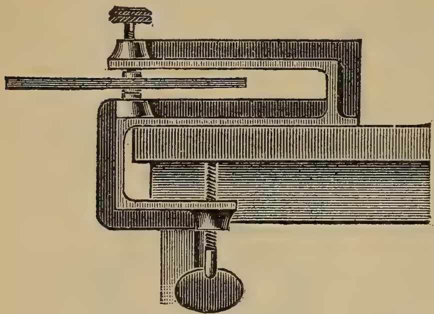


FIG. 135.

If the experiment is properly performed, the sand will be tossed about and gather in lines, as shown in Fig. 136.

Repeat the experiment, damping a corner of the plate, and drawing the bow across the middle of one of the edges.

Make a drawing showing the position taken by the sand.

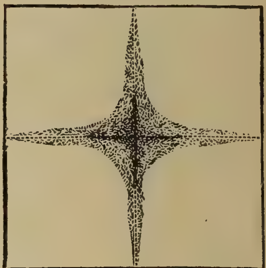


FIG. 136.

Experiment 8.

Repeat Experiment 7, using a circular plate, damping a point on the circumference and drawing the bow at a point 45° from it.

Vary the experiment by bowing the plate at other points.

Make a drawing of the position taken by the sand in each case.

The plates vibrate in divisions, or sections, separated from one another by nodal lines, or lines which remain nearly at rest. While one division moves upward, the adjoining one moves downward. The sand is thus tossed about and is soon thrown to the points of least motion.

7. Vibration of Air-Columns.

Experiment 9.

Insert a whistle[1] through a perforated cork placed in the end of a glass tube about three times as long as the whistle and 2 centimetres in diameter. Place in the tube some fine precipitated silica, or some cork dust made by filing a cork. Cork the open end of the tube (Fig. 137). Distribute the powder throughout the tube and blow on the whistle. Observe the motion of the powder.

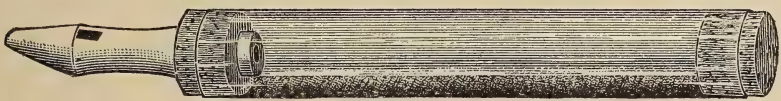


FIG. 137.

1. What evidence have you that the air within the tube is vibrating?

2. Are there any nodes, or points of rest, in the air column within the tube?

To show that the movement of the powder is not caused by the vibration of the glass or whistle, grasp these tightly in your hands and repeat the experiment.

The air driven through the mouth of the whistle strikes against the sharp edges of the lateral opening of the mouth-piece, thus causing vibrations of the air within the whistle and the tube. The vibrations are made visible by the vibrations of the light powder moving with the air.

8. Origin of Sound.

The preceding experiments in illustration of the vibrations of strings, rods, plates, columns of air, etc., show that in each case when sound was produced it was

[1] A common tin or wooden flageolet cut off at the orifice nearest the mouth-piece will answer.

accompanied by vibrations in some body. The most careful examination of all sounding bodies shows that this is always the case, and that **the sensation of sound has its origin in vibrations of some vibrating body.**

Vibrations which give rise to the sensation of sound are called **sonorous vibrations.**

9. Nature of Sound.

Sound is defined sometimes as a **sensation,** and sometimes as the **external cause of the sensation.**

As a sensation, it is an effect perceived normally by the ear.

As the antecedent cause of a sensation, it is defined as **that special condition of matter in virtue of which incidentally it may affect the organ of hearing.**

The term is generally used in the latter sense in physics.

CHAPTER XIII.

TRANSMISSION OF SOUND.

1. A Material Medium Necessary for Transmission of Sound.

Experiment 1.

Place on the plate of an air pump a thick tuft of cotton batting, and upon it place an alarm clock or a bell rung by clock-work or by an electric current (Fig. 138). Cover the whole with a receiver, and, when the bell is ringing, gradually exhaust the air from the receiver.

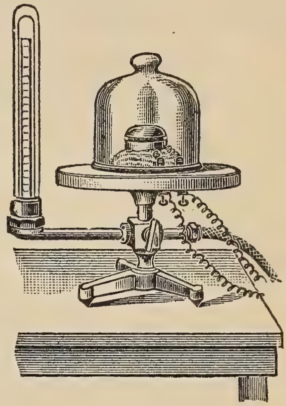


FIG. 138.

What change takes place in the sound as the air is exhausted?

When the exhaustion is as complete as it is possible to make it, let the air gradually into the receiver.

1. What change now takes place?

2. What therefore seems necessary to transmit the sound to the ear?

2. Sound Transmitted by Solids.

Experiment 2.

Repeat the last experiment, removing the batting and placing the sounding body on the plate of the pump.

1. How do your observations in this case differ from those made in the previous experiment?

2. How can you account for the difference?

Experiment 3.

Glue the centre of a thin board 6 or 8 inches square to the end of a pine rod 4 or 5 feet long and one inch square. Screw a hook into the other end of the rod, hang a watch on the hook and place your ear close to the board.

Can you hear the ticking of the watch?

Remove the rod, place the watch at the same distance and try whether the ticking can be heard through the air.

In which case is the sound transmitted with the greater distinctness?

Experiment 4.

Repeat the last experiment, placing the ear to the board when another person touches the end of the handle of a vibrating tuning-fork to the end of the rod, removes it and again touches it to the rod.

What changes in the distinctness of the sound are observed?

Experiment 5.

Place a watch on a table, bring your head near the watch and stop your ears so that the ticking cannot be heard. Now touch your forehead to the watch.

What is observed? Why?

Vary the experiment by touching the watch to your teeth and to other parts of your head.

3. Sound Transmitted by Liquids.

Experiment 6.

Unscrew a tuning-fork, which has been mounted on a resonance-box, from the box. Fill a tumbler or a glass jar nearly full of water and place to in the resonance-box. Now stick the handle of the fork into a large cork, excite the fork, and place the cork in the water (Fig. 139). Alternately raise the cork out of and lower it into the water.

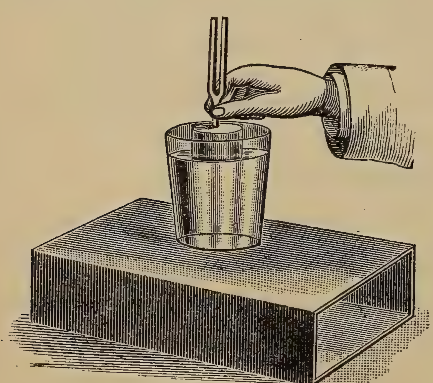


FIG. 139.

1. What changes in the sound are observed?

2. What media transmit the sound when the cork is in the water?

3. It is said that divers under water can hear sounds made on shore. How may this be possible?

The above experiments show **that a material medium is required for the propagation of sound, and that solids and liquids as well as gases transmit sound.**

4. How is Sound transmitted by a Medium?

Experiment 7.

Let a pebble drop into a body of water at rest. Describe the motion of the water surrounding the point where it entered the water.

Experiment 8.

Make a coil-spring about one inch in diameter and two or three feet long; stretch it between two pegs. Set one of the coils near the end vibrating by pulling it backwards with the point of a knife and letting it go. Describe the motion in the spring.

Whenever a vibratory disturbance is made in an elastic medium, as when a point on the surface of the water is disturbed by the pebble or a coil of the spring is made to vibrate, the disturbance is not confined to the region at first set in motion, but is propagated within the medium. The portions of the medium set in motion do not move onward carrying the disturbance but it is handed from one portion to the next in a form of wave motion.

In the case of the water the particles of water move up and down at right angles to the directions along which the waves advance, while in the coil-spring the coils move to and fro in the direction in which the disturbance is propagated.

The transmission of the vibrations in the coil-spring furnishes an illustration of the manner in which the vibrations of a sounding body, for example a tuning fork, are believed to be transmitted by the air.

As the prongs move-to-and fro, the air in contact with the fork is set vibrating. This air, in its vibration, causes the air surrounding it to vibrate, which in turn gives motion to the air beyond it, and so on. In this way the air in contact with the ear is finally set in vibration and the sound of the fork is heard.

5. Reflection of Sound—Echoes.

Experiment 9.

Cut from a sheet of cardboard a circular disc about 10 inches in diameter, cut out of the disc two sectors, as shown in Fig. 140, and mount it on the spindle of a whirling machine. Let one person rotate the disc, and at the same time blow on a toy trumpet held inclined to the plane of the disc, while another person goes to a distant part of the room and describes the changes which he observes in the sound given out by the trumpet.

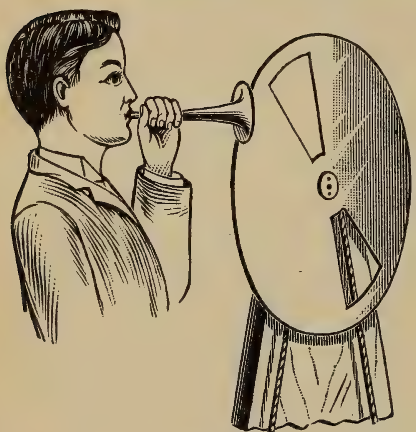


FIG. 140.

Is the effect different when the observer stands in different parts of the room?

The effect is due to interrupted reflections of the sound-waves. When the cardboard is in front of the trumpet the sound-waves are thrown back from its surface, and

the sound appears to the listener to increase in power. This experiment furnishes a simple illustration of a common phenomenon.

When sound-waves are not obstructed they are propagated, as we have learned, in all directions from the centre of disturbance; but when they encounter an obstacle in any direction they are reflected from the surface upon which they strike, and the direction is consequently changed.

Sound-waves obey the same laws of reflection as ether-waves. (See reflection of light.)

When an interval of time intervenes between a direct sound and its reflection from some distant object, for example, a hill, the latter is heard as an **echo.** The interval of time between the production of the original sound and the echo is the time taken for the sound-waves to travel to the reflecting body and back again.

Endeavor to produce an echo by placing yourself at a short distance in front of a large building situated in an open space, and shouting or singing. If you do not at first succeed, change your position, going nearer the building or receding from it, but always keeping yourself squarely in front of it.

QUESTIONS.

1. A street with houses on both sides runs north and south, and a church is situated at a little distance to the east of it. To a person walking down the eastern side of the street the sound from a bell in the church-tower seems to come from the west. Explain the reason, making a drawing to illustrate your answer.

2. In large buildings and in mountainous regions a succession of echoes is sometimes heard. Explain the reason.

3. A person is walking between two parallel walls which are near together, and hears a prolonged echo of each footstep. Explain how the echo is produced.

4. Why do deaf persons sometimes place their hands behind their ears to catch sounds?

5. How may an echo be made use of for determining approximately the velocity of sound in air?

6. Why do our footsteps in unfurnished dwellings sound so startlingly distinct?

7. Why do the echoes of an empty church disappear when the audience assembles?

8. Why is it that a sound will travel much further through a tube than through the open air?

9. At Carisbrooke Castle, in the Isle of Wight, is a well two hundred and ten feet deep and twelve wide. The interior is lined by smooth masonry. When a pin is dropped into the well, it is distinctly heard to strike the water. Explain the reason.

CHAPTER XIV.

MUSICAL TONES—PITCH, LOUDNESS AND QUALITY.

I.—Musical Sounds and Noises.

Musical sounds are the result of a regular succession of vibrations which follow a definite law, and produce an effect agreeable to the ear.

A noise is the result of a combination of vibrations which follow no law, or one so complex that the ear fails to understand or appreciate it.

The distinction then between musical sounds and noises is not absolute, but simply one of degree, depending on the complexity.

Musical sounds differ from one another in:

(1) Pitch,

(2) Loudness or intensity,

(3) Quality or Timbre.

II.—Pitch.

1. To Determine what the Ear Recognizes as Pitch.

Experiment 1.

Repeat Experiment 5, page 162, using an A-fork and a C-fork, which should be inserted side by side into the block with the opposite prongs of the two forks inclined to each other so that by drawing a rod between them they will be excited at the same time. Attach styles to the prongs nearest each other, excite the forks and obtain tracings of the vibrations on the same piece of smoked glass. Mark off the same length on each tracing and count the number of waves on each in this length.

Do the forks in the same period of time vibrate the same number of times?

If not, mark the fork which vibrates the faster.

Now bring to the ear first the one vibrating fork and then the other.

Which gives the higher or more acute note?

Experiment 2.

Fix on the spindle of a whirling-machine a toothed wheel (Fig. 141). Hold a card lightly against the teeth and rotate the wheel, at first slowly, then more and more rapidly. Observe the sound produced.

Experiment 3.

Have a series of holes punched at equal distances in a circular disc along a circle near its circumference. Mount the disc on the spindle of the whirling-machine (Fig. 142). Insert a piece of glass tubing, the bore of which is about the size of the holes in the disc, into a piece of rubber tubing. Place the glass tube before the ring of holes, rotate the disc, at first slowly, then more and more rapidly, and at the same time force air steadily through the tube.

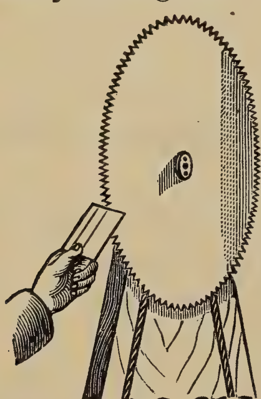


Fig. 141.

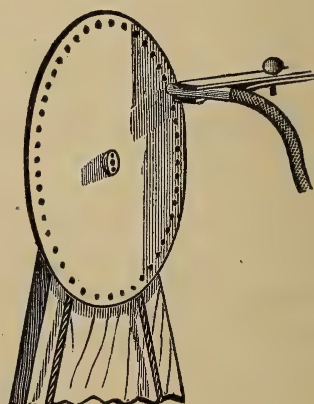


Fig. 142.

1. Describe the changes which take place in the sound produced in each of the above experiments as the velocity of the rotating wheel or disc is increased.

2. What is the cause of the sounds produced in the second experiment?

3. In which case is the frequency of the vibration the greater, when the wheel or disc rotates slowly or quickly?

The **pitch** of a musical note depends upon the **rapidity of the vibrations which enter the ear,** the greater the number of vibrations per second the higher the pitch of the note.

2. Limits of Audibility.

The sense of hearing varies widely in different persons. The ordinary ear is sensitive to vibrations ranging from 16 to 35,000 or 40,000 vibrations per second. The average range of the notes employed in music extends from 40 to 4,000 vibrations per second.

3. Upon What is the Pitch of a Vibrating String Dependent?

To answer this question we make use of a **monochord** or **sonometer.**[1] Fig. 143 shows the construction of the instrument. It consists of a long, narrow resonance box, provided at its ends with steel pins to which wires or

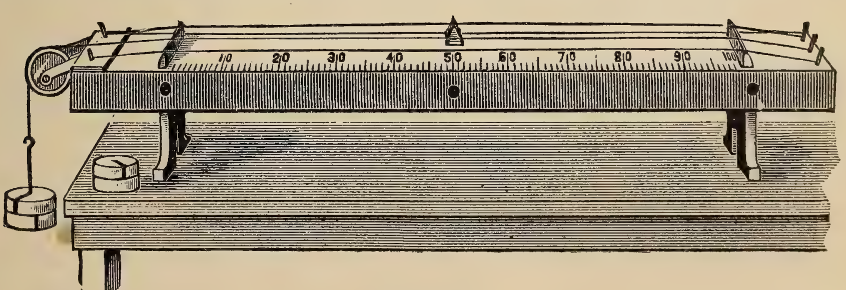


FIG. 143.

strings can be fastened. The wires pass over two fixed bridges, one being placed at each end near the pins.

[1] For manual training exercise, see Appendix, page 328.

The distance between these bridges is generally one metre. The wires are stretched either by turning the pins with a key, or by a weight. When a weight is used, the wire passes over a pulley placed at one end of the sonometer.

Movable bridges are provided to be used in changing the length of the part of any wire to be put in vibration.

Experiment 4.

Stretch by means of a weight a piano wire on the sonometer, excite the wire by plucking it, and mark the note. Now shorten the wire by inserting a movable bridge under it and again excite it.

Is the pitch of the note higher or lower than that given by the wire vibrating as a whole?

Experiment 5.

Remove the movable bridge, excite the wire and again mark the original note. Now add another weight to the stretching force and excite the string.

What change has increasing the tension of the wire made in the pitch of the note?

Experiment 6.

Take two piano wires of different diameters and stretch them in turn on the sonometer with the same weight.

Which wire gives, when excited, the higher note?

Experiment 7.

Procure two wires of the same diameter but of different densities, say steel and brass or copper, stretch them in turn on the sonometer with same weight.

Which gives the higher note? Which is the denser? (Consult a table of specific gravities.)

The above experiments show that the pitch of the note given by a vibrating string, or wire, depends on its length, its tension, its diameter, and its density; the shorter the wire, the greater the tension, the less the diameter, or the less the density, the higher the pitch of the note given by it.

Exact quantitive experiments, which are beyond the limit of this work, have determined the following **laws:**

1. **When the tension is constant the number of vibrations per second varies inversely as the length.**

2. **The number of vibrations per second varies as the square root of the tension.**

3. **The number of vibrations per second varies inversely as the diameter.**

4. **The number of vibrations per second varies inversely as the square root of the density of the material of which the string is composed.**

4. Upon what is the Pitch of a Vibrating Air-Column in a Tube Dependent?

Experiment 8.

Take the tube and whistle used in Experiment 9, page 165, and insert into the open end by means of a stiff wire, a cork which will slide up and down in the tube, just touching the sides.

Place the cork near the end and sound the whistle, noting the pitch of note given by it. Now push the cork in a short distance, sound the whistle and note the pitch. Repeat the experiment several times pushing the cork in a short distance each time.

What effect has shortening the air-column on the pitch of the note given by its vibration?

Draw the cork out until it is near the end of the tube, sound the whistle, remove the cork altogether and again sound the whistle.

In which case is the note the higher?

The above experiments show that the shorter the air-column, the higher the pitch of the note given by it, and that the pitch of the note given by the air-column in a tube or pipe open at the ends is higher than that in a pipe closed at one end.

The exact laws may be stated as follows:

1. The vibration-number of the note produced by a vibrating air-column within a tube varies inversely as the length of the tube.

2. A tube open at both ends gives a note whose vibration-number is double that given by a tube of the same length which is closed at one end.

III—Intensity of Sound.

5. Intensity and Amplitude of Vibration.

Experiment 1.

Repeat Experiment 1, page 160. Observe the string, and note the changes in the amplitude of its vibrations.

What change takes place in the amplitude of the vibration of the string as the sound grows weaker?

Experiment 2.

Repeat Experiment 5, page 162. Observe the tracing on the smoked glass.

What evidence have you that the intensity of the sound increases with the amplitude of vibration of the sonorous body?

6. Intensity and Density of the Medium.

Experiment 3.

Repeat Exp. 1, page 167.

1. What change takes place in the density of the air in the receiver as the exhaustion proceeds?

2. What change in the intensity of the sound accompanies this change in the density of the air in which the sound originates?

7. Intensity and Distance.

Does the intensity of a sound increase or decrease with an increase in distance from the point at which it originates?

8. Reinforcement of Sound—Consonance, Resonance.

Experiment 4.

Excite a tuning-fork, observe the loudness of the sound, and press the end of the handle against a table.

What change takes place in the loudness of the sound?

Excite the fork and observe the time the sound continues (1) when it is held in the hand, (2) when the end of the handle is pressed against the table.

1. In which case does the sound continue the longer?

2. What is the cause of the difference?

When the two were in contact, the fork communicated its vibrations to the table, a greater mass of air was set in vibration, and the intensity of the sound was consequently increased.

When the intensity of a sound of a vibrating body is re-inforced by the communication of its vibrations to a body of greater surface, thus generating air-waves of greater volume, the effect is called **consonance**.

Experiment 5.

Arrange apparatus as shown in Fig. 144. The glass tube should be from one to two inches in diameter and about fifteen inches long. Excite a C-fork and hold it over the tube, moving the tube up and down in the jar partially filled with water.

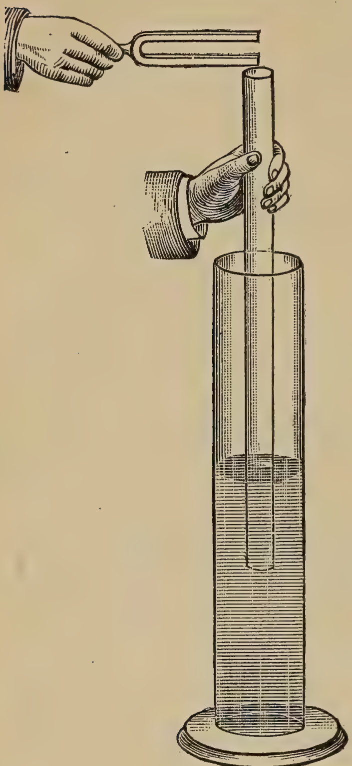


FIG. 144.

1. What changes in the intensity of the sound take place as the tube is moved up and down in the water?

2. What evidence have you that there is one particular length of the air-column in the tube which gives forth a maximum sound?

Repeat the experiment, using other forks.

Are the air-columns which give the maximum sounds with the different forks of equal length? If not, what is the relation between the length of the air-column and the rapidity of vibration of the fork?

The vibrations of the tuning-fork are re-inforced by synchronous vibrations of the air-column in the tube, and the intensity of the sound thus increased.

When the sound produced by a vibrating body is re-inforced by the vibrations which are produced in another body, tuned to vibrate in unison with it, the effect is called **resonance.**

III.—Quality.

9. Nodes and Loops.

Experiment 1.

Stretch a string on a sonometer and damp it at the centre by touching it lightly with a feather. Place a rider, made by folding a piece of paper into the form shown in Fig. 145, at the centre of one of the halves, and bow the string at the centre of the other half (Fig. 146).

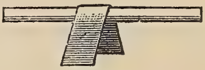


FIG 145.

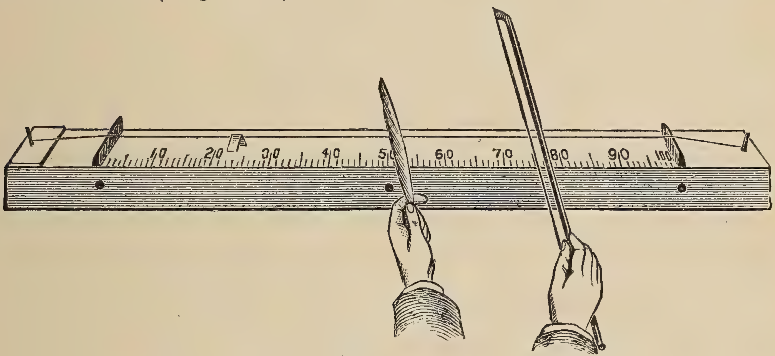


FIG. 146.

1. How does the rider behave? 2. How is the string vibrating?

Experiment 2.

Repeat the above experiment, damping the string at one-third its length from one end, placing riders on the string in the positions shown in Fig. 147, the middle one being at a point one-third of the length of the string from the end. Bow the string at the point shown.

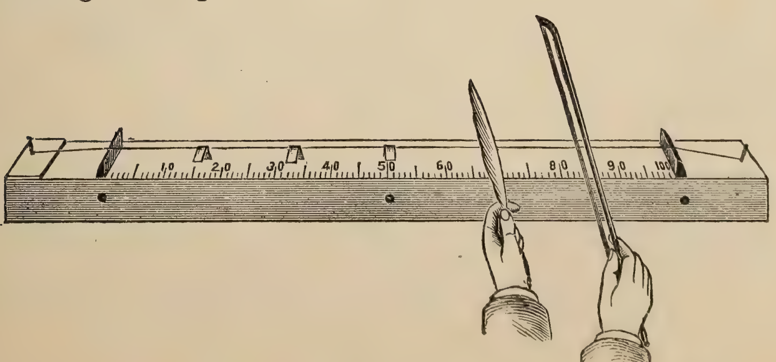


FIG. 147.

1. How do the riders behave?

2. Where are the points of least motion in the string? Where the points of greatest motion?

3. How is the string vibrating?

Experiment 3.

Repeat the last experiment, damping the string at a point (1) one-fourth, (2) one-fifth of its length from one end.

1. How does the string vibrate in each case?

2. How does the note which the string yields differ from that which it gives when it vibrates as a whole?

The above experiments show that a stretched string may vibrate not only as a whole, but may be made also to divide itself into a number of equal parts, each of which vibrates as an independent string (Fig. 148).

The points of no vibration are nodes or nodal points, and the centre of the part of the string between any two consecutive nodes is called a loop.

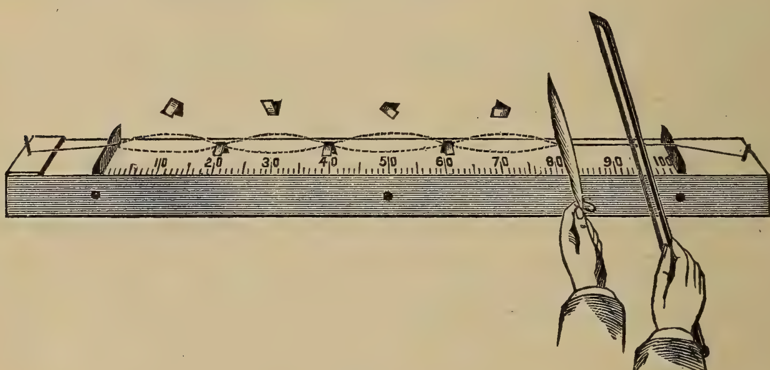


Fig. 148.

10. Overtones.—Quality or Timbre.

It is impossible to vibrate a string as a whole without, at the same time, causing it, to a greater or less extent, to divide and vibrate also as segments. The fundamental note of the string will, therefore, be mingled to a greater or less degree with its higher tones.

What is true of strings is also true of other sounding bodies. Smaller vibrations are superposed upon the larger, and the higher tones which they yield mingle with those given by the larger.

All the higher tones which mingle with the fundamental tones given by any sounding body are called **overtones.**

The combination of the overtones with the fundamental tones determines what is called the **quality,** or **timbre,** of a sound. If the same note is produced by a flute, a piano, a violin, or by the human voice, the pitch is the same but the effect is different, although the notes may be, as nearly as possible, of the same loudness. In fact, if the same note is successively sung with the same intensity by two persons, the effect is different. The difference is a difference in quality, and is caused by the difference in the number and the relative strength of the overtones.

The quality or timbre of a sound, therefore, is that characteristic which depends on the complexity of its vibrations.

IV.—Musical Instruments.

In most of the common forms of musical instruments the tones are produced either by vibrating strings or by vibrating air-columns.

The violin, the harp, and the pianoforte are examples of the former, and the horn and the organ of the latter.

FIG. 149.

11. The Violin.

The violin consists of a wooden resonance box of the well-known form shown in Fig. 149.

At one end of the box is attached a neck, or finger-board, and at the other a tail-piece. The strings are stretched between these two projections by being tightened by turning pins at the extremity of the neck. The strings are raised above the box by a bridge supported in the interior by a sound-post. The bridge is made convex in form to allow the bow with which the strings are excited to be drawn across each string without interfering with the others. There are four strings, the tones of which can be modified at will by the player to give various combinations by shortening the lengths of the strings by pressure with the fingers.

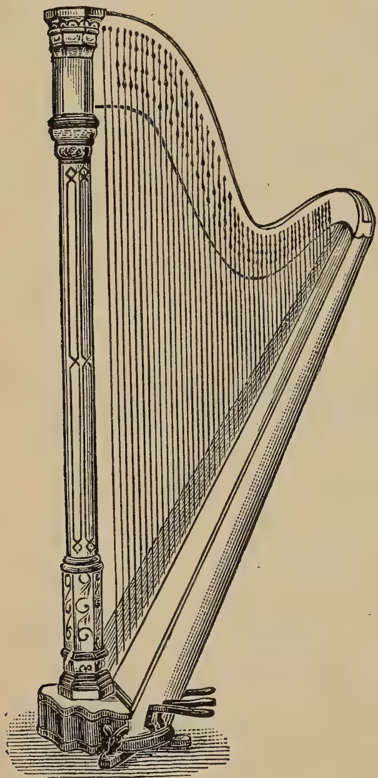


FIG. 150.

12. The Harp.

The modern harp (Fig. 150) consists of a triangular frame made to stand on one of its corners. It usually has forty-three strings stretched from the top to one of the sides which is constructed as a resonance chamber. The strings give tones which may, within definite limitations, be modified by means of a pedal mechanism. It is played by exciting the strings with the fingers.

13. The Pianoforte.

In the pianoforte the strings are stretched across a strong iron frame to which is attached a wooden sounding-board. The strings are set in vibration

by hammers which are connected with the keys by a mechanism which enables the player to modify at will the intensity of the sounds. It is an instrument of fixed tones, that is, there is a string, or combination of strings, and a corresponding key for every tone the instrument is to produce.

14. The Horn. The horn in its simplest form consists of a mouth-piece connected with a tube which ends in a bell-shaped expansion. (Fig. 151.)

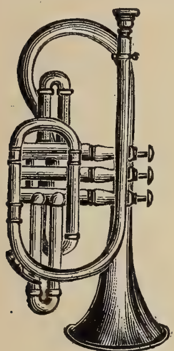


Fig. 151.

The various forms of the instrument differ mainly in the shape of the mouth-piece and the bell, in the form and number of the bends or folds in the tube, and in the combination of valves or slides connected with the tube to produce a variety of tones. It is sounded by blowing into the mouth-piece, and its tones are controlled by pressure of the lips and by manipulating the valves or slides which change the character of the air-columns set in vibration.

15. The Organ.

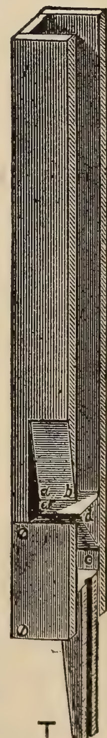


Fig. 152.

The organ consists of a combination of pipes, which are made to sound by compressed air supplied by a bellows and stored in a wind-chest. The instrument is played by keys and pedals which operate the valves that control the supply of air to the individual pipes. The pipes differ in form, length and material, but all belong to one or other of two main classes known as flue-pipes and reed-pipes. Fig. 152 shows the construction of

a common form of the flue-pipe. Air is forced through the tube T into the chamber C. The compressed air escapes from this chamber by a narrow slit *ed*, and, striking against the narrow bevelled edge or lip *ab*, imparts a vibrating motion to the column of air in the pipe, the result of which is a musical note dependent for its pitch, as we have seen (Art. 3, page 178), on the length of the pipe.

In the reed-pipe the air-column is set in vibration by a tongue, or a spring within the tube, which is made to vibrate by the admission of the compressed air. The musical note is dependent for its pitch on the length of the tongue, and its quality is determined to a great extent by the length and form of the pipe within which the reed is placed.

CHAPTER XV.

NATURE AND SOURCES OF HEAT.

I.—Nature of Heat.

We have seen, page 156, that heat is one of the forms in which energy becomes known to us. Its nature is not perfectly understood; but since most of the phenomena connected with it may be explained by this theory, *heat is believed to be the energy possessed by a body in virtue of the motion of its molecules.*

II.—Sources of Heat.

Heat is regarded as a form of energy because its sources are other forms of energy, and it in turn may be transmuted into other forms.

The following are some of its sources:

1. Heat from Mechanical Action.

(1) From Friction.

Experiment 1.

Rub a button on a piece of cloth.

1. What evidence have you that it has received heat?

2. Why does iron when filed become hot?

3. Why is oil placed in the journals of car axles?

4. If a small brass tube is filled with water, corked, and then made to rotate rapidly while it is squeezed between two pieces of wood, it will receive sufficient heat to cause the water to boil and to eject the cork. Explain the reason.

(2) From Percussion.

Experiment 2.

Place a piece of lead on a block of iron and strike it a few blows with a hammer.

1. What evidence have you that it has received heat ?

2. What has become of the energy of bodily onward motion that was in the hammer ?

3. A bullet is fired against an iron target and is picked up almost too hot to be held in the hand. Explain the reason.

FIG. 153.

(3) From Compression.

Experiment 3.

Place a piece of tinder in a tube (Fig. 153) closed at one end and containing air. Push a piston into it quickly.

1. What takes place ? Explain the reason.

2. Why do air pumps become heated when compressing air into the pneumatic tires of bicycles ?

2. Heat from Chemical Action.

Experiment 4.

Pour 100 c.cm. of water into a beaker, and carefully stir into it 10 c.cm. of sulphuric acid.

What evidence have you of the generation of heat ?

Experiment 5.

Cut a thin shaving from the end of a stick of phosphorus, dry it with blotting paper, put it on a plate, and place on it some powdered iodine. Neither the phosphorus nor the iodine should be touched with the fingers. The phosphorus should be held in forceps and cut under water. The iodine may be placed on a piece of paper and poured on the phosphorus.

What takes place ?

Most chemical changes are accompanied by changes in the quantities of heat possessed by the bodies taking part in them. This is the source of the heat resulting from combustion, which is but a particular case of chemical action.

3. Heat from an Electric Current.

Experiment 6.

Connect three or four galvanic cells[1] as shown in Fig. 154. Attach a copper wire to each pole, and complete the circuit by attaching to the free end of one of the copper wires a piece of fine platinum or iron wire four or five inches long, and

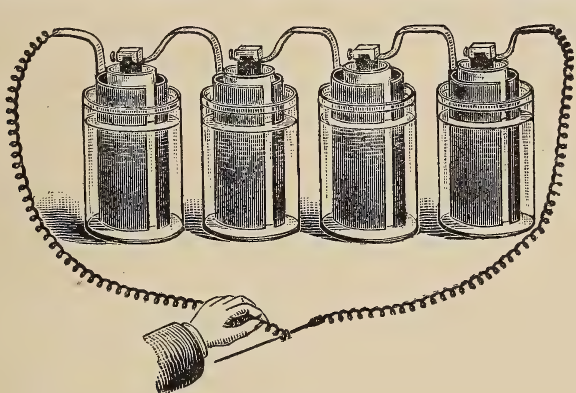


FIG. 154.

touching the end of the other copper wire to the end of the platinum or iron wire. (The fine iron wire used by florists answers well.) Slide the copper wire along the iron wire up towards the other copper wire.

What evidence have you of the production of heat?

Whenever an electric current meets with resistance in a conductor heat results. The fine iron wire offers considerable resistance, and if a sufficiently strong current

[1] The best grades of dry cells in common use for gas engine ignition and other purposes will be found the most satisfactory for this and the other experiments in this book requiring an electric current.

be made to pass through it, the wire will become white-hot and burn up.

How are the filaments in incandescent electric lamps heated?

4. Heat from Radiant Energy from the Sun.

This is by far our most important source of heat. We shall consider at a later stage the theory regarding the transmission of the sun's heat to us in the form of radiant energy.

In the following chapters we shall discuss some of the **effects** of heat, viz.: **expansion, change of temperature,** and **change of state.**

CHAPTER XVI.

EXPANSION THROUGH HEAT.

1. In Solids.

Experiment 1.

Take a brass ball and ring (Fig. 155), such that ordinarily the ball will just pass through the ring. Heat the ball intensely in the flame of a Bunsen burner and try to pass it through the ring.

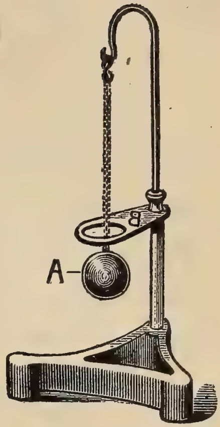


Fig. 155.

1. What change has taken place in the volume of the ball?

2. Will it pass through the ring when it has cooled?

3. How could you make the ball pass through when hot?

Experiment 2.

Measure the dimensions of a small rectangular piece of iron with a micrometer caliper, heat it, and measure its dimensions again while hot.

How has the size of the iron been affected by heating?

Experiment 3.

Arrange apparatus[1] as in Fig. 156. A metal rod is fixed at one end while the other presses against a compound lever so

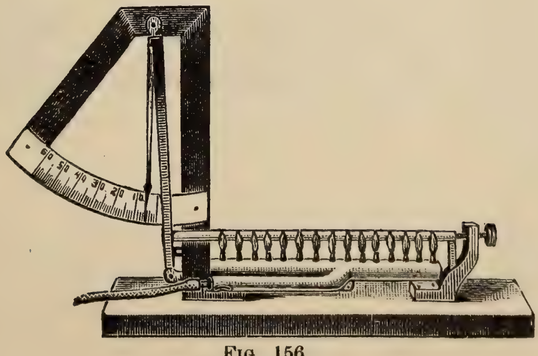


Fig. 156.

[1] For manual training exercise, see Appendix, page 329.

arranged that the slightest elongation of the rod is indicated on a scale. Apply heat to the rod and watch the end of the pointer on the scale.

1. What do you observe?
2. What does the experiment prove?
3. Allow the rod to cool. What is the result?

Experiment 4.

Prepare a compound bar made up of two strips, one of iron and the other of copper, riveted together as shown in Fig. 157. Heat this bar strongly in the flame of a Bunsen burner.

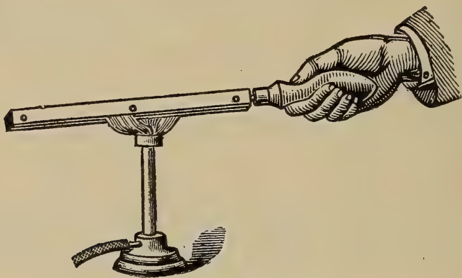


FIG. 157.

1. What is the result?
2. Which metal is on the concave side?
3. Which metal is the more elongated through heat?

What result would you expect if the compound bar were made very cold? Try.

From these experiments we see that **solids expand through heat, and some expand more than others.**

2. In Liquids.

Experiment 5.

Fill a flask with water, insert a perforated rubber stopper through which has been thrust a small glass tube open at both ends, and attach a paper scale to the tube as shown in Fig. 158. Apply heat to the flask and watch the column of water in the glass tube.

1. What is the result?

2. Which expands the more rapidly through heat, water or glass?

3. Prepare another flask and tube identical with the first, filling it with alcohol instead of water. Place the two in the same bath of hot water and watch the result.

It is found that **liquids as well as solids expand through heat, and liquids in general expand more rapidly than solids, while some liquids expand more rapidly than others.**

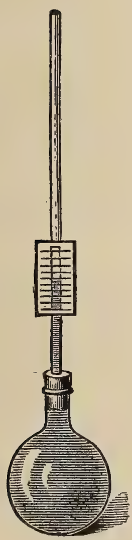


FIG. 158.

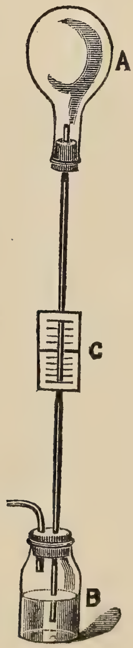


FIG. 159.

3. Gases.

Experiment 6.

Arrange apparatus as in Fig. 159. A is a glass flask filled with air connected by a tube open at both ends with a bottle B partly filled with water. Apply heat to A and observe the end of the tube below the surface of the water in B.

1. What is the result ?

2. What does it prove ?

3. Allow A to cool and observe the water in the tube. What follows ?

4. What does this result prove ?

We find that **gases expand very rapidly through heat.**

QUESTIONS.

1. A glass stopper stuck in the neck of a bottle may be loosened by subjecting the neck to violent friction by means of a string. Explain.

2. Pipes of cast-iron for conveying steam or gas, if of considerable length, must have expansion joints. Explain the reason.

3. Why does a blacksmith heat a waggon tire before adjusting it to the wheel ?

4. The rate at which a clock runs depends on the length of its pendulum. Would you expect it to keep accurate time both in summer and in winter ?

5. If a large leaden bullet is cast in a mould a small cavity is found near its centre. What is the reason of this ?

6. Why are the rails on a railroad track not laid quite close together ?

7. Why is the tone of a piano not the same in a cold as in a warm room ?

8. Why is the sheet of zinc under a stove liable to become puckered ?

9. In which season would you expect the tension of the telegraph wires to be the greater, summer or winter ? Why ?

CHAPTER XVII.

TEMPERATURE.

I.—Nature of Temperature.

Experiment 1.

Heat a piece of iron in the flame of a Bunsen burner and drop it into a small vessel containing cold water.

1 What change takes place in the water?

2. What change takes place in the iron?

3. When do these changes cease?

When two bodies, like the iron and the water above, are in such a condition that on being brought together one gains heat while the other loses it, they are said to be at different temperatures. The body gaining heat is said to have a lower temperature than the one losing heat. If two bodies are brought together and neither gains heat from the other, these bodies are said to have the same temperature. Hence we may say that **temperature is the condition of a body considered with reference to its power of receiving heat from, or communicating heat to, another body.**

II.—Designation of Temperature.

We can describe a particular temperature only by reference to another temperature taken as a standard, that is, by stating how much this particular temperature is higher or lower than the standard temperature. Thus we require a **standard temperature** and also a **unit of difference of temperature.**

1. Standard Temperature.

The most convenient standard temperature is the temperature at which ice melts. This temperature is easily obtained by mixing ice and water, and is constant under ordinary conditions. It is usually called the **freezing-point.**

2. Unit of Difference of Temperature.

The unit of difference of temperature used is a fraction of the difference between the temperature of melting ice and the temperature of the steam rising from water boiling under the average pressure of the air at the sea-level (the boiling point). Two units are in use, viz., the **Fahrenheit degree,** which is $\frac{1}{180}$ of this difference, and the **Centigrade degree,** which is $\frac{1}{100}$ of the same difference.

1. How many Fahrenheit degrees are equal to one Centigrade degree?

2. How many Centigrade degrees are equal to 36 Fahrenheit degrees?

3. A temperature 108 Fahrenheit degrees above the freezing point is how many Centigrade degrees above the freezing point?

4. A temperature 15 Centigrade degrees above the freezing point is how many Fahrenheit degrees below the boiling point?

5. Which has the higher temperature, a body 40 Centigrade degrees above the freezing point or a body 100 Fahrenheit degrees below the boiling point?

6. What is the difference between the two temperatures above?

III.—Determination of Temperature—Thermometer.

If you place your hand in contact with a body at a very low temperature you experience a sensation which leads you to say that the body is cold, and if you place it in contact with a body at a much higher temperature you experience a sensation which leads you to say that the body is warm or hot. But your heat sense does not enable you to determine the temperature of a body with any degree of accuracy.

Experiment 1.

Prepare three beakers of water, A, B, and C. Make A as hot as you can bear to hold your hand in, make C very cold by putting in ice if necessary, and make B such a temperature that it feels neither hot nor cold. Hold a finger of your right hand in A and one of your left hand in C for one or two minutes. Now immediately put both fingers in B.

1. How does B feel to your right hand?
2. How to your left hand?
3. Is B hot or cold?

This experiment clearly shows that our estimation of the temperature of a body by means of our heat sense depends very much upon the temperature of that part of our own body used in making the estimation.

Experiment 2.

Place your hand in contact with a large piece of iron in a moderately warm room, and with the same hand touch a piece of wood in the same room.

1. If both the iron and the wood have been in the room for a long time, and hence have been for some time in contact with the same air, have the iron and the wood different temperatures?

2. Do you experience the same sensation on touching them?

3. Which feels the colder?

From this experiment it is seen that our estimation of the temperature of a body by means of our heat sense depends on the material of the body as well as upon its temperature. Therefore for various reasons we cannot depend upon the heat sense for the accurate determination of temperature.

Change of temperature in a body is accompanied by other changes, and by observing some of these we may indirectly determine the temperature. Any instrument constructed to enable us to estimate the temperature of a body is called a **thermometer.** Of all the changes accompanying change of temperature, change of volume is generally the most convenient for estimating change of temperature, since it can be observed by means of our sense of sight, perhaps the most exact of all our senses.

3. Mercury Thermometer—Construction.

Procure a glass tube of very fine uniform bore, blow a bulb on one end, and a funnel on the other (Fig. 160). Pour some mercury into the funnel and gently heat the bulb. The air expands and a part of it bubbles out through the mercury in the funnel. Allow the bulb to cool. The air pressure on the surface of the mercury in the funnel forces some of the mercury through the tube into the bulb. Now heat the bulb above the flame of a Bunsen burner until the mercury boils long enough to expel all the remaining air. As the bulb cools the mercury vapour will condense and mercury will run

down the tube and completely fill the bulb and tube. Again heat the bulb, and the contained mercury will expand, causing some to overflow at the open end of the tube. While the mercury is overflowing, direct a blow-pipe flame upon the open end and seal it up, at the same instant removing the bulb from above the flame.

The instrument now contains a fixed mass of mercury, which is free to contract or to expand within certain limits, and the construction is such that a small change in the volume of the liquid is easily observed.

FIG. 160.

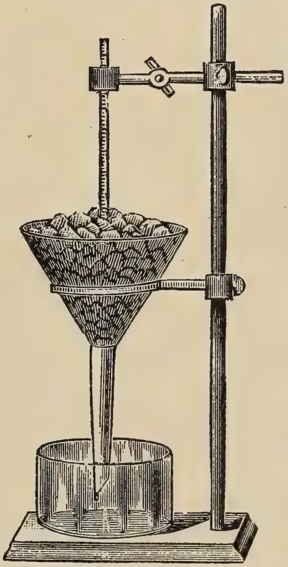


FIG. 161.

4. Finding the Freezing Point.

On a convenient support place a funnel, fill it with snow or melting ice, and place in it the bulb of your thermometer, as shown in Fig. 160. The mercury, contracting faster than the glass, will drop down the tube. When the mercury ceases to fall, indicating that its temperature is no longer changing, and hence that it has reached the temperature of the melting ice, mark with a file on the tube the position of the upper surface of the mercury.

Experiment 3.

Test in the manner described above whether the freezing point has been properly marked on the thermometer you are using in your laboratory.

5 Finding the Boiling Point.

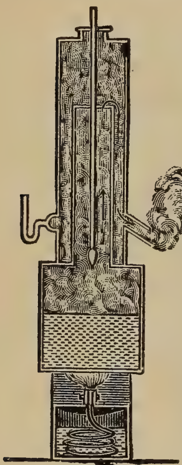


Fig. 162.

Next expose the bulb and tube to the steam rising from pure water boiling under a pressure of 760 mm. of mercury, as in Fig. 162, taking care that the bulb is not plunged into the water, but remains suspended above it. Mark with a file on the tube the termination of the mercury column.

Experiment 4.

Test the boiling point of the thermometer you are using. If you cannot fit up a boiler of the form shown in Fig. 162, use a flask in the manner shown in Fig. 168, page 210. Keep the bulb of the thermometer about 1·5 cm. above the surface of the water in the flask.

Name some possible sources of error in your determination.

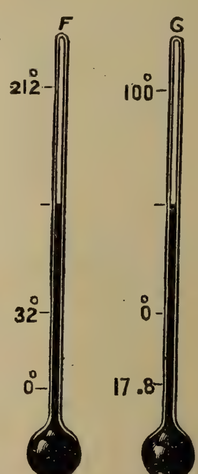


Fig. 163.

6. Graduation.

Having thus marked the freezing and the boiling points, the next thing is to graduate the instrument.

If you wish to make a Fahrenheit thermometer, mark the freezing point 32° and the boiling point 212°, and divide the intervening portion of the stem into 180 equal parts, extending the graduations above the boiling point and below the freezing point. If you wish to make a Centigrade thermometer, mark the freezing point 0°

and the boiling point 100°, and divide the intervening portion of the stem into 100 equal parts, extending the graduations as in the previous case. In Fig. 163 both methods of graduation are represented.

1. Why is it necessary that the bore of the tube should be of uniform size throughout?

2. Why should the bore be very small?

7. Comparison of Scales.

1. What temperature on the Centigrade scale is the same as 0° (zero) on the Fahrenheit scale?

2. What temperature on the Centigrade scale is the same as 100° on the Fahrenheit scale?

3. How many Fahrenheit degrees above freezing point is 41° on the Fahrenheit scale (41° F.)? How many Centigrade degrees then is it? What is its reading on the Centigrade thermometer?

4. How many Centigrade degrees is 10° C. from the freezing point? How many Fahrenheit degrees is it? How many Fahrenheit degrees is it from the Fahrenheit zero? What is its reading on the Fahrenheit scale?

5. Find the Fahrenheit readings corresponding to the following Centigrade readings: 12°, 75°, –10°, –40°.

6. Find the Centigrade readings corresponding to the following Fahrenheit readings: 60°, 180°, –5°, –30°.

7. The temperature of a room is T° C. What is its reading on the Fahrenheit scale?

8. The temperature of a room is T° F. What is its reading on the Centigrade scale?

9. Hence state a rule for transforming a reading from the Fahrenheit to the Centigrade scale.

10. What temperature on the Fahrenheit scale is the same as —273 on the Centigrade scale?

8. Alcohol Thermometer.

For the determination of very low temperatures a thermometer filled with alcohol instead of mercury is made use of, as alcohol does not freeze except at an exceedingly low temperature.

9. Air Thermometer.

The apparatus of Experiment 6, page 193, may be used as a thermometer, the position of the water in the tube being an indication of the volume, and hence of the temperature of the air in the flask A. This instrument is very delicate, since a slight change in the temperature of a mass of air is accompanied by a very considerable change in its volume, if the pressure to which the air is subjected remains unchanged.

The fact that the reading of an air thermometer is influenced by the pressure of the surrounding atmosphere prevents its use for ordinary purposes.

10. Differential Thermometer.

For determining slight differences of temperature between two neighbouring points the instrument represented in Fig. 164 is often used. In it two bulbs are connected by a bent tube, the lower part of which is filled with some coloured liquid so arranged that both extremities are at the same level when the two bulbs are at the same temperature.

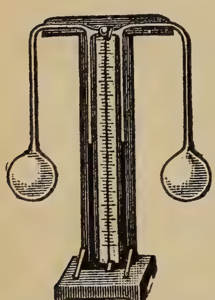


Fig. 164

What will be the position of the extremities of the liquid if the right hand bulb is warmer than the left?

IV.—Maximum Density of Water.

Experiment 1.

Fill a flask with water at 10° or 20° C., and insert a perforated rubber stopper through which have been thrust a glass tube open at both ends and a thermometer. Press down the stopper until the water rises a few inches in the tube. Take care that no air is caught in the flask. Place the flask in a vessel containing a mixture of ice and salt as in Fig. 165. Observe the thermometer and also the column of water in the tube.

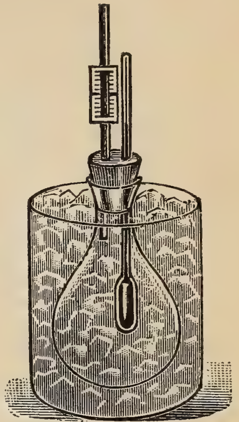


FIG. 165.

1. What change do you observe in the temperature of the water in the flask?

2. What change do you observe in the volume of the water?

3. Does the water continue to contract as its temperature falls?

4. At what temperature has the water its least volume?

5. What change of volume takes place when the water begins to freeze?

The experiment shows us that **mass of water has its least volume and therefore its greatest density at 4° C.** It is a matter of common observation that **water expands in freezing.**

V.—Relation Between the Volume and the Temperature of a Gas.

11. Charles' Law.

Careful quantitive experiments and calculations show that **the volume of a given mass of any gas at constant pressure increases for each rise of temperature of 1° C. by a constant fraction (about $\frac{1}{273}$) of its volume at 0° C.**

This is generally known as Charles' Law.

12. Absolute Temperature.

If the volume of a given mass of any gas, at a constant pressure, increases for each rise in temperature of 1° C. by $\frac{1}{273}$ of its volume at 0° C., and the pressure of the given mass of gas, at a constant temperature, varies inversely as its volume, then its pressure is increased $\frac{1}{273}$ of the pressure at 0° C. for every degree its temperature is increased, or at 273° its pressure is double of what it is at 0°. *If the pressure were to continue to diminish at the same rate,* at – 273° C., the gas would exert no pressure on the containing vessel. The pressure of the gas is supposed to be due to the impacts of its molecules upon the surface upon which it is said to press, and, therefore, when it exerts no pressure its molecules must be supposed to be at rest and the gas to be therefore at its lowest possible temperature. Hence – 273° C. is called **absolute zero.** Temperature reckoned from this point is called **absolute temperature,** that is, the absolute temperature = centigrade reading + 273°.

From a consideration of the above it will be seen that Charles' law may be stated as follows:

The volume of a given mass of gas at a constant pressure varies directly as the absolute temperature.

QUESTIONS.

1. If the absolute temperature of a gas is doubled and the pressure kept constant, what change takes place in (*a*) its mass, (*b*) its volume, (*c*) its density?

2. If the pressure of a gas is doubled and its volume kept constant, what change may take place in (*a*) its mass, (*b*) its density, (*c*) its absolute temperature?

3. If the pressure of a gas is lessened so that it becomes one-half the original pressure, while the temperature is kept constant, what change takes place in (*a*) the volume, (*b*) the density of the gas ?

4. If the volume of a given mass of gas is 100 c.cm. at 27° C., what will the volume become at —23° C. if the pressure is kept constant ?

5. If the volume of a given mass of gas is 1 litre at a temperature 0° what will be its volume at a temperature of (*a*) 100° C., (*b*) —13° C, the pressure remaining constant ?

6. At what temperature will a gas, the volume of which is 1 litre at a temperature of 0° C., become 1200 c.cm. in volume, the pressure remaining constant ?

7. What change will be produced in the pressure of a gas by changing its temperature from 0° C. to 273° C., the volume remaining constant ?

8. What will be the volume of a mass of air measuring 1 litre at 0° C., if the temperature is raised to 273° C. and the pressure doubled ?

9. A closed tube filled with air at 0° and under atmospheric pressure is gradually heated. If the tube can safely stand a pressure of 4 atmospheres, to what temperature may it be heated ?

10. Find the volume at 27° C. and under a pressure of 760 mm. of mercury, of a mass of air which, at 45° C. and under a pressure of 1500 mm., occupies 10 c. ft.

Since the volume varies directly as the absolute temperature, and the temperature is **reduced** from 45° C. to 27° C. the volume will be **reduced** and become

$$\frac{273+27}{273+45} = \frac{300}{318} \text{ of the original volume,}$$

when the pressure remains constant ; but since the volume varies diversely as the pressure, and the pressure is **reduced** from 1500 mm. to 760 mm. of mercury the volume will be **increased** and become

$$\frac{1500}{760} \text{ of the original volume.}$$

Hence the volume required will be

$$\left(10 \times \frac{300}{318} \times \frac{1500}{760} = \right) \text{ c. ft.}$$

11. The volume of a certain mass of gas at a temperature of 17° C., and under a pressure of 600 gm. per sq. cm. is 1000 c.cm; what will be its volume at a temperature of 27° C. and under a pressure of 1000 gm. per sq. cm.?

12. A mass of gas occupies a volume of 22·4 litres at the temperature 10° C. when the barometer stands at 70 cm., what volume will it occupy at the temperature 0° C. when the barometer stands at 76 cm.?

13. To what temperature must a gas be heated in order that its volume may become double of what it is at 20° C.?

14. A litre of hydrogen weighs 0·0896 gm. at 0° and 760 mm. barometric pressure. Find the weight of a litre at 20° C. and 766 mm. pressure.

15. The density of air at 0° C. and 760 mm. pressure is 1.29 grams per litre. What is its density at 273° C. and 1000 mm. pressure?

CHAPTER XVIII.

CHANGE OF STATE.

I.—Solid to Liquid and Liquid to Solid.

1. Fusion.

Experiment 1.

Partly fill a large vessel with water at a high temperature, say 90° C., and in it place a small vessel partly filled with water at a low temperature, say 10° C., and place a thermometer in each. Observe the changes of temperature in the two vessels for a minute or two. Now fill the smaller vessel with wet snow or finely broken ice at 0°, and observe the change of temperature in the two vessels while the snow is melting.

1. What change occurs in the temperature of the water in the large vessel in the first case?

2. What in the temperature of the water in the small vessel?

3. Which body loses heat?

4. Where does this heat go?

5. What does this heat do?

6. What change takes place in the temperature of the water in the large vessel in the second case?

7. What in the temperature of the contents of the small vessel?

8. Does a change of any kind take place in the contents of the small vessel?

9. Which body loses heat?

10. Where does it go?

11. What does this heat do?

Experiment 2.

Heat a thin glass tube about 5 mm. in diameter and draw it out into a fine thread, as shown in Fig. 166. Heat some

FIG. 166.

paraffin wax in a test-tube and by suction draw some of the liquid paraffin into the fine part of the tube. Close the point by fusing the extremity in the flame. Allow the paraffin to solidify, and fasten, by means of a rubber band or thread, the tube to a chemical thermometer (Fig. 167). Place the tube and thermometer in a beaker of water, and gradually warm the water. Stir the water constantly and notice its temperature when the paraffin in the thin tube melts. Allow the water to cool and note the temperature at which the paraffin solidifies.

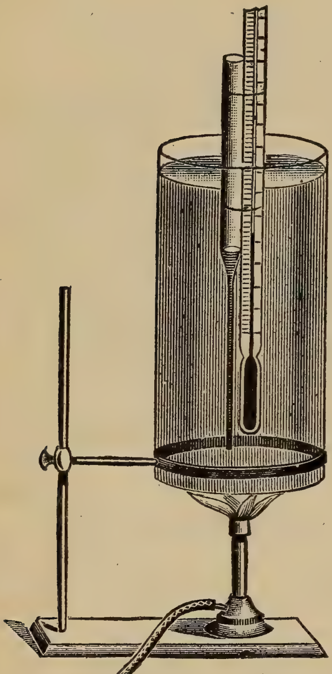


FIG. 167.

1. At what temperature does the paraffin melt?

2. At what temperature does it solidify?

3. Find the melting points of other bodies in the same way.

4. How do their melting points compare with their points of solidification?

2. Solidification.

Experiment 3.

Melt some paraffin wax in a beaker, and when it is all melted place the beaker in another vessel slightly larger and partially filled with cold water. Observe the temperature of the water from time to time.

1. What change takes place in the paraffin?

2. What change takes place in the temperature of the water?

3. Is any heat given out by the paraffin while it is solidifying? How do you know?

3. Laws of Fusion.

The above and similar experiments prove the following laws:—

(1) **A substance begins to melt at a temperature which is constant for the same substance, if the pressure is constant.**

(2) **The temperature of a solid remains unchanged while fusion is taking place.**

(3) **The temperature of solidification is the same as the temperature of fusion.**

(4) **If a substance expands on solidifying, like ice, its melting point is lowered by pressure; if it contracts, like wax, its melting point is raised by pressure.**

4. Solution.

Experiment 4.

Partly fill a beaker with water and note the temperature. Measure out two or three grams of ammonium nitrate and note its temperature. Put the ammonium nitrate in the water and stir the mixture with a thermometer.

1. What is the temperature of the water at first?

2. What is the temperature of the ammonium nitrate?

3. What temperature does the mixture reach?

4. What change do you observe besides change of temperature?

5. What form of energy disappears?

6. What is the result produced by this energy?

Experiment 5.

Break some pieces of ice into small fragments and mix with common salt. Place a thermometer in the mixture.

1. What is the temperature of the ice and of the salt before the mixture ?

2. What temperature does the mixture reach ?

3. What change besides change of temperature takes place ?

4. What energy disappears ?

5. What result does this energy produce ?

6. Does this energy cease to exist ?

7. If not, where can it be ?

8. If a stone is thrown upwards it moves slower and slower as it rises and at last stops. What has become of the energy due to the velocity with which it started ?

II.—Vapourization and Liquefaction.

5. Ebullition.

Experiment 1.

Partly fill a flask with cold water and insert a perforated stopper containing a tube open at both ends, and a thermometer, as represented in Fig. 168. Place the flask over the flame of a Bunsen burner and let it remain until the water has boiled for some time, carefully watching the thermometer meanwhile.

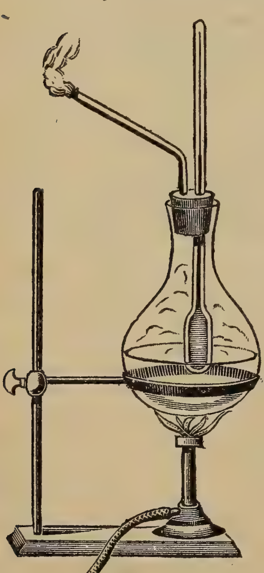


Fig. 168.

1. What change takes place in the temperature of the water at first ?

2. Where does the heat come from that effects this change ?

3. At what temperature does the water begin to boil ?

4. After the water has begun to boil, what change takes place in its temperature ?

5. Does the water continue to receive heat after it has begun to boil?

6. If so, what does this heat do?

Experiment 2.

1. With the apparatus shown in Fig. 168 determine (*a*) the temperature of pure water when boiling; (*b*) the temperature of the steam rising from it.

2. Determine these temperatures in the case of water having some common salt in solution.

3. Mix three parts of water with one of alcohol and determine the temperature of the boiling liquid and also of the steam.

4. Sprinkle some iron filings in the flask with pure water and repeat the experiment.

Experiment 3.

Arrange apparatus as in Fig. 169. Heat the water in the flask containing the thermometer until it begins to boil.

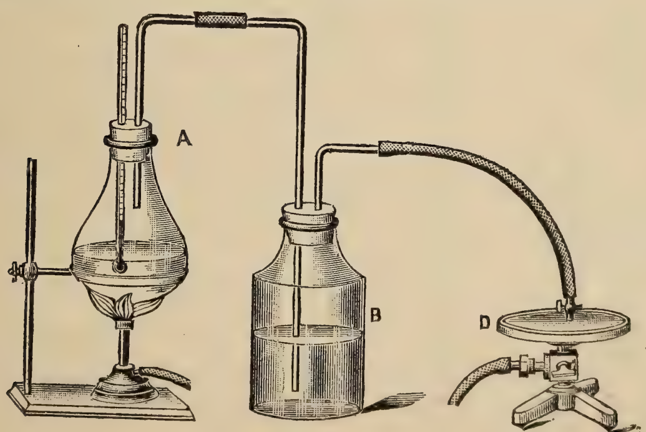


FIG. 169.

Then, removing the lamp, by means of the attached air pump exhaust the air from the apparatus, thus lessening the pressure on the surface of the hot water.

1. What takes place when you begin to work the air pump?

2. What change of temperature do you observe?

3. What is the lowest temperature at which you can make the water boil?

Experiment 4.

Vary Experiment 3 by inserting the delivery-tube from A into a test-tube containing mercury to a depth of about 3 cm. instead of connecting it with the bottle B and the air pump.

In doing this, wrap a cloth around the test-tube, which should be held over a pan, heat gently the flask A, and, when the steam is coming freely but not too rapidly from the delivery-tube, push it down to the bottom of the mercury in the test-tube. As soon as the mercury begins to sputter remove the delivery-tube.

Observe the thermometer throughout the whole process.

1. Does any change take place in the temperature of the boiling water while the tube is in the mercury? If so, what is the cause of the change?

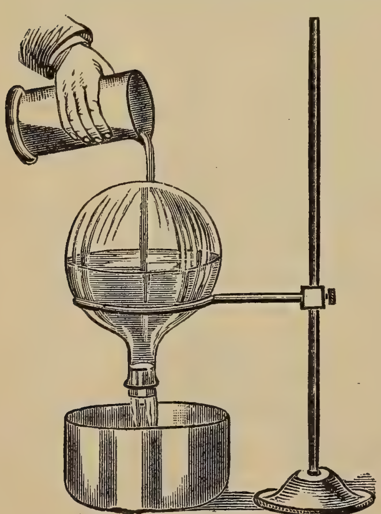


FIG. 170.

To answer this question consider the effect of inserting the delivery-tube into the mercury on the pressure upon the surface of the water in the flask.

Experiment 5.

Half fill a flask with water and boil for a minute or two so that the escaping steam may expel all the air. While it is boiling vigorously, remove the flame and at the same instant close the flask with a rubber stopper. Invert the flask and support it on a retort stand

as in Fig. 170. Pour cold water over the flask and observe the result. Now pour very hot water over the flask and see what happens. Again pour cold water over the flask or, still better, immerse the flask in cold water.

1. What happens when cold water is first poured over the flask?

2. What happens when the hot water is poured on?

3. What takes place when the cold water is again poured on, or the flask is immersed in cold water?

4. With a thermometer determine the temperature of the water in the flask at the end of the experiment.

5. What does the flask contain after it has been closed by the stopper?

6. What change in its contents is produced by pouring cold water on it?

7. Can you see any connection between the result of this experiment and that of the previous one?

6. Evaporation.

Experiment 6.

Wrap a piece of muslin about the flask A of the air-thermometer (Fig. 159, page 193) and set the instrument in an open window where there is a draught. Pour ether on the muslin drop by drop and watch the result.

1. What becomes of the ether?

2. What change in temperature does the air-thermometer indicate?

Experiment 7.

Pour a few drops of ether on the back of your hand.

1. What change of state takes place?

2. What evidence have you that your hand loses heat?

3. What does this heat do?

4. What effect on the rate of evaporation follows from an increase in the temperature of a liquid, other conditions remaining the same?

5. From which will a given volume of water evaporate more quickly, a narrow deep dish or a broad shallow one?

6. Why do we set the apparatus in a draught in Experiment 6?

The quiet vapourization taking place at the surface of a liquid is called **evaporation.** The **rate** at which evaporation takes place depends upon the nature of the liquid, its temperature, the amount of the vapour of the liquid in the surrounding space, and also the presence in the surrounding space of other gases.

7. Saturation—Dew Point.

The **quantity** of a particular vapour which a given space can hold depends upon the vapour and the temperature, but is independent of the presence of other gases. A space containing all of a particular vapour which it is capable of holding is said to be **saturated** with that vapour. The temperature at which the water vapour present in the atmosphere would saturate the space it occupies is called the **dew point.**

8. Liquefaction.

Experiment 8.

Prepare the apparatus shown in Fig. 171. Two flasks are connected by a long tube, the greater part of which is surrounded by a much larger tube so arranged that cold water

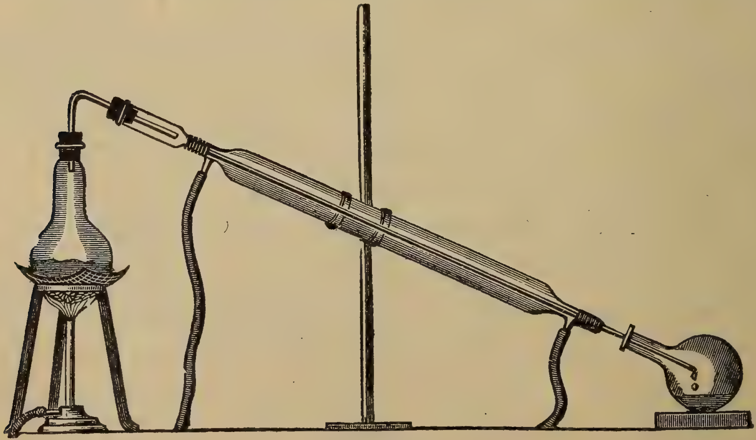


Fig. 171.

may be made to circulate in the space between the two tubes.

Partly fill the higher flask with a mixture of alcohol and water in the ratio of one of alcohol to three of water. Boil the mixture. The steam in passing through the cold tube is condensed, and the resulting liquid is caught in the lower flask. After you have collected a small quantity of liquid in the lower flask, take away the flame. Cool both flasks and pour part of the contents separately into two evaporating dishes. Try to set fire to the liquids with a lighted match.

1. Are the two liquids the same ?

2. Which contains the greater proportion of water ?

3. How could you obtain fresh water from sea water ?

4. How could you obtain salt from sea water ?

5. What change takes place in the temperature of the water used to cool the tube ?

6. Whence comes the heat required to produce this change ?

These and other experiments establish laws of ebullition as follows :—

(1) **A liquid begins to boil at a temperature which is approximately constant for the same substance if the pressure is constant.**

(2) **The temperature of the boiling liquid remains unchanged until the whole is vapourized.**

(3) **Increase in pressure raises the boiling point of all liquids.**

(4) **The boiling point of water is raised by the presence of salts in solution.**

These experiments also show that heat is expended in changing the state of a body from a solid to a liquid and from a liquid to a vapour, and that heat is produced when the reverse change takes place.

Heat expended in changing the state of a body without changing its temperature is called latent heat.

The heat disappearing in this case is expended in doing work upon the molecules of the body whose state is changed, causing them to occupy positions with respect to one another different from what their mutual attractions would tend to make them occupy. The molecules, in consequence of occupying such positions, possess potential energy equivalent to the energy expended in giving them these positions, just as a weight raised above the surface of the earth possesses potential energy equivalent to the energy expended in raising it.

QUESTIONS.

1. Why does the temperature generally moderate when snow falls?

2. Does rain bring cool weather or does cool weather bring rain?

3. Why do you feel cooler when sitting in a draught?

4. Why is a person liable to take cold when his clothes are damp?

5. Does dew fall?

6. What causes the formation of drops of water on the outside of a pitcher containing ice-water when it is brought into a warm room?

7. Why does "fanning" cool the face?

8. Why is it difficult to cook food in boiling water at a high elevation above the sea level?

9. Why is an iceberg frequently enveloped by a fog?

10. Why does sprinkling water on the floor have such a cooling effect upon the air of a room?

11. How low a temperature may be determined by means of a mercurial thermometer ?

12. Why is one's breath visible on a cold day ?

13. It is known that, near the earth's surface, for every 960 feet of vertical ascent above the sea level the boiling point of water is lowered 1° C.

What is the cause of this lowering of the boiling point ? How could the above fact be made use of in determining experimentally the heights of mountains ?

14. What effect has (*a*) the freezing of water, (*b*) the evaporation of water, (*c*) the condensation of water vapour, (*d*) the melting of ice on the temperature of the atmosphere ?

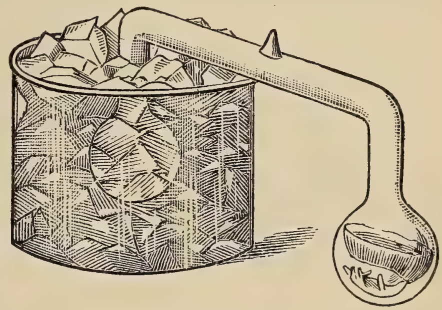


Fig. 172.

15. A tube having a bulb at each end has one of its bulbs half filled with water, the remaining space containing nothing but water vapour. The empty bulb is surrounded by a freezing mixture (Fig. 172), and after a time it is found that the water in the other bulb is frozen. Explain.

CHAPTER XIX.

MEASUREMENT OF HEAT.

I.—Latent Heat.

1. Temperature and Quantity of Heat.

The temperature of a body and the **quantity of heat** it contains must be carefully distinguished. The former has been defined (page 195) and is a **condition** depending, probably, upon the average energy possessed by each molecule, while the latter is a **quantity of energy,** the energy possessed by a body in virtue of the vibrations of its molecules.

2. Heat Unit.

The thermometer enables us to find the temperature of a body, but it does not enable us to determine the quantity of heat possessed by the body. For example, a gram of water at 100° C. has a higher temperature than a kilogram of water at 50° C., but the latter contains a far greater quantity of heat. To measure heat, as to measure any other quantity, we must select as a unit a quantity of the same kind. The unit in general use is the quantity of heat required to raise the temperature of a unit mass of water one Centigrade degree. We thus have a heat unit corresponding to each unit of mass. **The heat required to raise the temperature of one gram of water one Centigrade degree is called the calorie, and is the unit most frequently used.**

It has been ascertained that the quantity of heat required to raise the temperature of a mass of water 1° is approximately the same at all parts of the scale between 0° and 100°, hence one way of measuring a particular quantity of heat is to observe by how many degrees this heat will change the temperature of a known mass of water.

1. How many calories will raise the temperature of 25 gm. of water 10 degrees?

2. How much heat is given out by the cooling in hot-water pipes of 100 Kgm. of water from 100° C. to 80° C.?

3. 100 gm. of water at 80° C. are mixed with 40 gm. at 10° C. What is the temperature of the mixture?

4. A flask containing 500 gm. of water at 10° C. is placed over a steady Bunsen flame, and in five minutes the water begins to boil. How much heat does the flame give up to the flask during one second?

3. Latent Heat of Fusion of Ice.

Let us determine the amount of heat required to melt one gram of ice.

Experiment 1.

Obtain a thin glass beaker that will hold about one litre, wrap it in flannel, and pour into it 500 grams of hot water. Place a thermometer in the water to note its temperature. Weigh out 100 gm. of dry snow or finely broken ice and drop it into the beaker, rapidly stirring the mixture with the thermometer until the snow or ice is all melted. Observe the temperature of the water just as the snow is all melted.

Temperature of water at first $(T) = \ ^\circ ?$
Temperature of snow at first $= 0^\circ$
Temperature of water when snow is melted $(T_1) = \ ^\circ ?$

Amount of heat given out by the water in the beaker at first

$$= 500\,(T - T_1) \text{ calories.}$$

This heat melts the snow and raises the temperature of the resulting water from 0° to T_1°.

Amount of heat required to raise from 0° to T_1° the temperature of the 100 gm. of water formed by melting the snow.

$$= 100\ T_1 \text{ calories.}$$

Hence amount of heat required to melt the 100 gm. of snow

$$= \{ 500\ (T - T_1) - 100\ T_1 \} \text{ calories.}$$

Therefore amount of heat required to melt one gram of snow or ice

$$= \frac{500\ (T - T_1) - 100\ T_1}{100} \text{ calories.}$$

$$= \qquad \text{calories ?}$$

Experiment 2.

Bore a hole in a block of ice, and pour into it 10 grams of water at a known temperature (T°C), then immediately cover the hole with a slab of ice. After a few minutes remove the cover and suck up into a pipette all the water from the hole. Carefully determine the mass of this water.

Mass of water removed (m)	=		grams ?
" " put in	=	10	"
∴ " ice melted	=	$(m - 10)$	"

The 10 grams of water put in are cooled from T° to 0°, and hence the heat lost by this water = 10 T calories.

Therefore the amount of heat required to melt $(m - 10)$ grams of ice without changing its temperature = 10 T calories.

Therefore the amount of heat required to melt one gram of ice

$$= \frac{10\ T}{m - T} \text{ calories.}$$

$$= \qquad \text{calories ?}$$

The amount of heat required to melt a unit mass of any substance is called the latent heat of fusion of that substance.

Careful experiments show that it requires approximately 80 calories of heat to melt one gram of ice. This fact is usually expressed by saying that the latent heat of fusion of ice is 80.

How should we express the same fact if we were to make our statement with reference to the Fahrenheit degree?

4. Latent Heat of Vapourization of Water.

Let us now find the amount of heat required to change a gram of water into steam without changing its temperature.

Experiment 3.

Pour 500 grams of water into a flask which will hold about one litre. Carefully note the temperature of the water and place the open flask over the flame of a Bunsen burner. Observe the time that elapses before the water begins to boil. Allow the water to boil for ten minutes or more, taking careful note of the time. Weigh the water which remains in the flask.

Temperature of water at first	(T) =	°?
Time required to raise water to the boiling point	(t) =	seconds?
Time during which the water is boiling	(t_1) =	seconds?
Quantity of water remaining	(m) =	grams?

Quantity of heat received from the Bunsen flame in t seconds

$$= 500\ (100 - \mathrm{T})\ \text{calories}.$$

Quantity of heat received from the Bunsen flame in t_1 seconds

$$= \frac{t_1}{t} 500\,(100 - \mathrm{T})\ \text{calories.}$$

But this heat evaporates $(500 - m)$ grams of water at 100°.

Therefore the quantity of heat required to evaporate one gram of water without changing its temperature is

$$\frac{\frac{t_1}{t} 500\,(100 - \mathrm{T})}{500 - m}\ \text{calories.}$$

$$= \qquad \text{calories ?}$$

Experiment 4.

Prepare apparatus as shown in Fig. 173. A is a flask containing water. B is a trap intended to catch any liquid

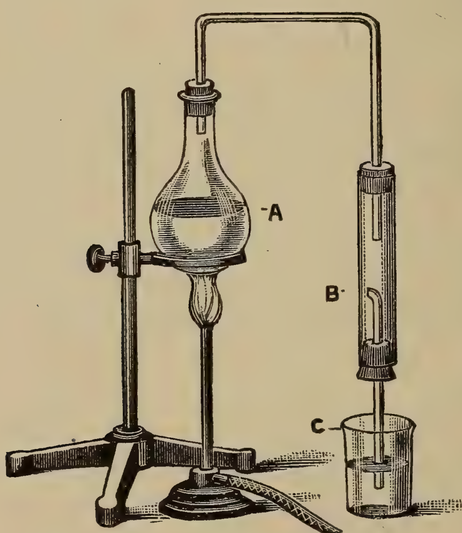


FIG. 173.

that may escape from A or may be condensed in the tube. C is a thin glass beaker containing 100 grams of water.

Taking C away apply heat to A until the water in it boils freely and steam is escaping from the open tube. Now

carefully note the temperature of the water in C, wrap it in flannel, and place it as shown in the diagram. Keep stirring the water in C with a thermometer, observing the temperature from time to time. Allow the boiling to continue until the water in C has reached a temperature near the boiling point. Carefully note this temperature and immediately remove C. Weigh the water in C.

Temperature of water in C at first (T) = ?
Temperature of water in C at last (T_1) = ?
Quantity of water in C at last (m) = grams ?

($m - 100$) grams of steam is condensed in C and cooled from 100° to T_1°.

The heat arising from this raises the temperature of 100 grams of water from T° to T_1° and therefore equals

$$100\,(T_1 - T) \text{ calories.}$$

The heat given out by the ($m - 100$) grams of water resulting from the condensation of the steam in cooling from 100° to T_1° is $(m - 100)\,(100 - T_1)$ calories.

Therefore the heat produced by the changing of ($m - 100$) grams of steam into water must be

$$\{ 100\,(T_1 - T) - (m - 100)\,(100 - T_1) \} \text{ calories.}$$

Therefore the amount of heat produced by the condensation of one gram of steam is

$$\frac{100\,(T_1 - T) - (m - 100)\,(100 - T_1)}{m - 100} \text{ calories.}$$

$$= \text{calories ?}$$

Experiments such as the above show that the quantity of heat required to change one gram of water into steam without changing the temperature is approximately 537

calories, and that the same quantity of heat is produced when one gram of steam is changed to water.

The quantity of heat required to change a unit mass of any liquid into vapour without changing its temperature is called the latent heat of vapourization of that liquid.

Hence we say that the latent heat of vapourization of water is 537.

Careful experiments show that in all cases the heat which disappears (is rendered latent) when a solid is changed to a liquid, or a liquid is changed to a vapour, again appears as heat when the reverse change takes place.

1. How much heat is required to melt 100 gm. of ice?

2. How much heat is produced by the liquefaction of 100 gm. of steam?

3. Ten grams of steam at 100° will melt how much ice at 0°?

II.—Specific Heat.

5 Capacity for Heat.

Experiment 1.

Pour melted paraffin into a flat circular vessel to the depth of about an inch. After the paraffin has cooled, remove the cake and support it as shown in Fig. 174. Procure a number of balls of different materials, lead, tin, copper, zinc, iron, etc., and of the same mass. Heat the balls to the same temperature in a vessel of boiling water. Taking them from the water, place them on the cake of paraffin and observe the result.

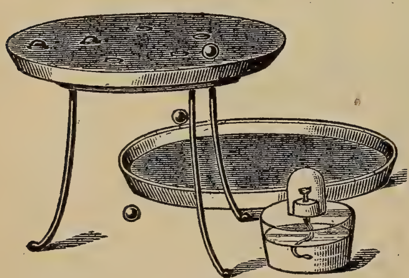


Fig. 174.

1. What takes place as each ball gives up some of its heat to the paraffin?

2. Are the balls cooled through the same number of degrees before ceasing to give up heat to the paraffin?

3. Is the result the same in all cases?

4. What produces the result in each case?

5. Which ball gives up the greatest quantity of heat in cooling from the temperature of the water bath to that of the paraffin?

The above experiment indicates that equal masses of different substances give out different quantities of heat in cooling through the same range of temperature, but it does not enable us to compare those quantities with any degree of accuracy.

The quantity of heat required to change the temperature of a unit mass of any substance 1° is called the capacity for heat of that substance.

6. The Calorimeter.

To determine accurately the quantity of heat given out by a particular body in cooling through a known range of temperature, an instrument called a calorimeter is used. One form of calorimeter is shown in Fig. 175. It consists of three metal vessels separated from one another by layers of broken ice. A pipe leads from the middle vessel to the outside, through which the water formed by the melting of any of the ice in this vessel will run. The inner vessel is to contain the hot body, and the layer of ice between the outer and middle vessels is to prevent any of the ice in the middle vessel from being melted by heat from outside. To use this calorimeter, heat the body to be experimented upon to a known temperature, and, removing the covers, drop the

hot body into the inner vessel, quickly replacing the covers. As the hot body cools, the heat it gives out goes to melt the ice in the middle vessel, and the resulting water runs out and is collected and weighed.

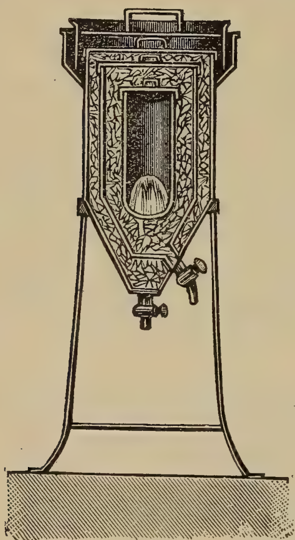


Fig. 175.

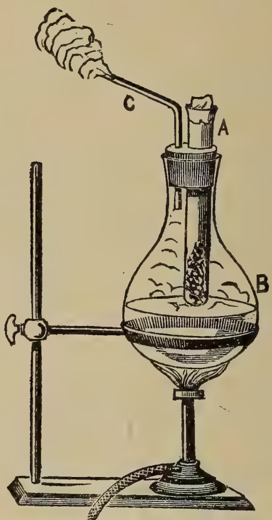


Fig. 176.

7. To Find the Amount of Heat given out by One Gram of Lead in cooling One Degree.

Experiment 2.

Prepare the apparatus shown in Fig. 176. In the dry test-tube A place 50 grams of granulated lead. Place a Bunsen burner under the flask and boil the contained water until you are sure that the lead has reached the temperature of the steam (100° C.). Remove the covers from your calorimeter, pour the lead from A into the inner vessel, and quickly replace the covers. Carefully collect and weigh all the water which flows from the middle vessel of the calorimeter.

Instead of using the calorimeter the heated lead may be placed in a hole bored in a block of ice, and covered with a

slab of ice. When the lead has ceased to melt the ice it is withdrawn, and the water removed from the hole with a pipette, and weighed.

Mass of water collected (m) = grams ?

Hence the heat given out by 50 grams of lead in cooling from 100° to 0° is the heat required to melt m grams of ice = $80m$ calories. Therefore the amount of heat given out by one gram of lead in cooling one degree is

$$\frac{80\,m}{50 \times 100} \text{ calories.}$$

$$= \qquad \text{calories ?}$$

The ratio of the quantity of heat required to raise the temperature of any mass of a substance 1° to the quantity of heat required to raise the temperature of the same mass of water 1° is called the specific heat of that substance.

Hence the quantity of heat required to change a mass (m gm.) of any substance (specific heat = s) through T° of temperature equals

$$(m\text{Ts}) \text{ calories.}$$

1. What is the specific heat of the lead in the above experiment ?
2. Determine the specific heat of zinc, iron, sand, etc.

Experiment 3.

Determine the mass of some shot.

Mass (m) = grams ?

Heat the shot in steam to a temperature of 100° as in Experiment 2.

Determine the mass and temperature of some water.

$$\text{Mass } (m_1) = \quad \text{grams ?}$$
$$\text{Temperature } (T_1) = \quad ?$$

Place the water in a beaker, or better in a thin metal vessel polished on the outside (a lemonade shaker answers well), surround the beaker with some wool or batting.

Pour the shot into the water, stir the two together, and when the two have reached the same temperature determine the temperature.

$$\text{Temperature } T_2 = \quad {}^\circ ?$$
$$\text{Heat gained by water} = m_1 (T_2 - T_1) \text{ calories.}$$

Heat lost by shot $= m\ (100 - T_2)\ x$ calories if x is the specific heat of the shot.

But heat lost by shot = heat gained by water,

$$\text{or, } m\ (100 - T_2)\ x = m_1\ (T_2 - T_1)$$

$$x = \frac{m_1\ (T_2 - T_1)}{m(100 - T_2)} = \quad ?$$

8. Transformation of Heat into Mechanical Energy—Steam Engine.

Heat is one of the principal sources of mechanical motion. In fact, modern industrial development has been to a great extent dependent on the invention of machines for utilizing heat for this purpose. Of these machines, the steam engine, which is a device for transforming the energy stored in steam into mechanical motion, is the most important.

In its simplest form, it consists of a piston made to move backwards and forwards in a cylinder by the

expansive force of steam applied alternately to its two faces.

Fig. 177 shows the essential working parts of a modern engine. The steam from the boiler in which it is gener-

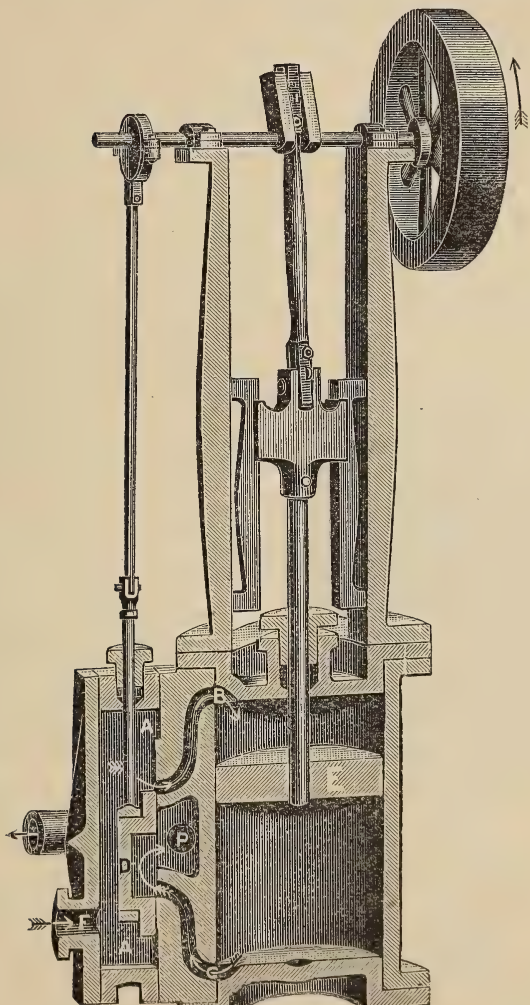


FIG. 177.

ated is lead by a pipe F into a steam-chest A, from which it is admitted to the cylinder at the ends by ports B and

C. These ports are connected alternately with the steam-chest and an exhaust-pipe P leading to the outside air by a slide-valve D made to move backwards and forwards in the steam-chest. Fig. 177 shows the port B connected with the steam-chest. The steam, therefore, is entering the upper part of the cylinder and forcing the piston E down, while the steam in the lower part of the cylinder is escaping by the port C and the exhaust pipe P with which it is now connected. In the meantime the slide-valve is moving upwards, and, when the piston reaches the bottom, the port C is connected with the steam-chest and the port B with the exhaust pipe as shown in Fig. 178. Steam now enters the lower part of the cylinder and forces the piston upwards, while the steam in the upper part of the cylinder escapes by the port B and the exhaust-pipe P. A to-and-fro motion of the piston is thus kept up which is transformed into a rotary motion by connecting it with a balance wheel by a piston-rod, cross-head and guides, connecting-rod and crank-shaft, as shown in Fig. 177. The slide-valve is moved by a rod connected to an eccentric wheel mounted on the crank-shaft.

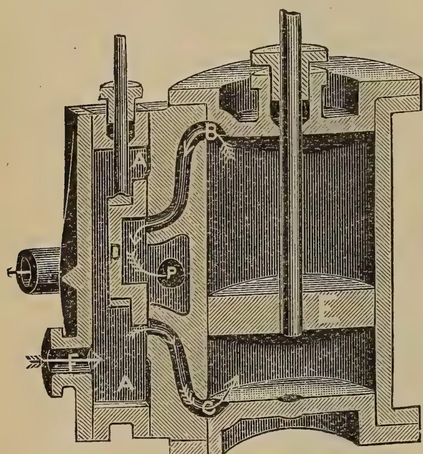


FIG. 178.

QUESTIONS.

1. If 10 lbs. of water at 12° C. is mixed with 40 lbs. of water at 90° C., find the temperature of the mixture.

2. Fifty grams of ice are placed in 520 grams of water at 19·8° C. If the resulting temperature is 10·5° C., what is the latent heat of fusion of ice?

3. Steam is passed into a mass of 495 grams of water at 15·2° until the temperature becomes 35·4°. The mass of water and condensed steam is now 512 grams. What is the latent heat of vapourization of water?

4. The latent heat of fusion of ice is 80; find

   (*a*) What mass of water at 90° C. will melt 100 grams of ice.

   (*b*) What mass of ice must be dissolved in a litre of water at 4° C. to reduce the temperature of the water to 2° C.

   (*c*) The resulting temperature when 30 grams of ice are dropped into 100 grams of water at 50° C.

   (*d*) The specific heat of brass if a piece weighing 80 grams, heated to 100° C., melts 9 grams of ice when placed in an ice calorimeter.

5. The latent heat of vapourization of water is 537; find

   (*a*) The resulting temperature when 25 grams of steam at 100° are passed into 300 grams of ice-cold water.

   (*b*) How many calories will be required to convert one litre of water at 4° C. into steam at 100° C.

   (*c*) How many grams of steam at 100° C. will just melt 10 grams of ice at 0° C.

6. If 100 grams of a metal are heated to 100° C. and placed in 80 grams of water at 10° C. the resulting temperature is 20° C. What is the specific heat of the metal?

CHAPTER XX.

TRANSMISSION OF HEAT.

It is a matter of common experience that heat has a tendency to pass from a warmer to a colder body or from a warmer to a colder part of the same body, and that a tendency to equalization of temperature is manifest in all bodies so placed that heat can pass from any one to the others.

We shall now consider some of the modes by which this diffusion of heat takes place.

I.—Conduction.

Experiment 1.

Thrust one end of a copper wire 4 or 5 inches long into the flame of a spirit lamp or Bunsen burner, and hold the other end in the hand. Touch your fingers to points nearer the flame.

1. What evidence have you that heat is being transmitted from the flame to the hand?

2. What transmits this heat?

Experiment 2.

Repeat Experiment 1, using instead of the wire a piece of glass rod.

What difference do you observe in the result?

The heat is said to be transferred by the wire from the flame to the hand by **conduction,** and the wire is

said to be a better **conductor** than the glass, which transfers the heat very slowly.

Conduction is the transmission of heat from hotter to colder parts of a body, or from a hot body to a colder one in contact with it without any visible motion of the parts of the bodies.

We have seen (Art. 1, page 48) that whenever two bodies whose velocities are different come in contact with each other there is a transference of energy. Just as the energy of bodily onward motion is transferred when two bodies whose speeds are different come in contact, so the energy of molecular motion, or heat, is supposed to be transferred when two bodies the average energies of whose molecules, that is whose temperatures, are different are made to touch.

We have learned (Experiment 1 and 2, page 197) that bodies, which have really the same temperature often appear to have, when touched with the hand, different temperatures. This is due to the relative conducting power of the body in contact with the hand. The intensity of the sensation depends upon the rate at which molecular energy is transferred to or from the hand; and this is dependent on the difference in temperature between the hand and the body when first brought in contact, and upon the conductivity of the body. If a body is a very poor conductor, the film in contact with the hand almost at once reaches the temperature of the hand.

1. Why do iron fixtures appear colder than the wood in a cold room and warmer than the wood in a very hot room ?

2. Silver is a better conductor of heat than the metal of which plated spoons are made. How could you distinguish between a solid silver spoon and a plated one?

3. Why are the handles of (*a*) coffee-pots, (*b*) ice pitchers, made of substances which are poor conductors of heat?

1. Relative Conductivities of Solids.

Experiment 3.

Take rods of copper, glass, iron, bone, etc., and place one end of each in a beaker containing boiling water. Allow them to stand for a few minutes and touch the fingers to the exposed ends.

Which are good conductors and which bad?

Experiment 4.

Take a rectangular vessel (Fig. 179), and pass through openings closed with perforated corks, rods of different substances, say copper, brass, iron, lead, glass, and wood, all of the same diameter and length. Coat the portions outside the opening with a thin layer of paraffin wax, and fill the vessel with water kept at the boiling point by means of lamps placed under the vessel. When the line of separation between the melted and unmelted parts of the wax on each rod no longer moves along the rod, measure the length of the melted portion on each rod.

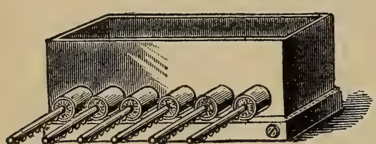


FIG. 179.

1. Arrange the substances of which the rods are made in the order of their conductivities.

2. Which are usually the better conductors, metals or non-metals?

2. Practical Applications.

Experiment 5.

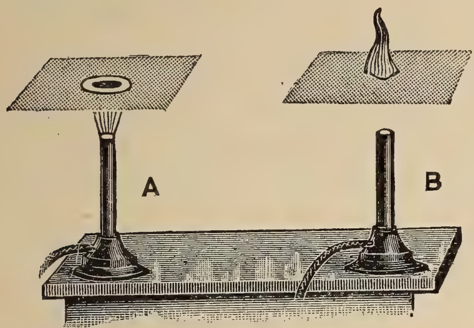


FIG. 180.

Depress upon the flame of a spirit lamp or Bunsen burner a piece of fine wire gauze, as shown in Fig. 180 A.

1. What effect has it upon the flame?

2. Is there any gas above the gauze?

To answer this question apply a lighted match above the gauze.

Experiment 6.

Hold the gauze about half an inch above the gas burner, turn on the gas and light it above the gauze (Fig. 180 B).

Does the flame pass through the gauze?

The explanation of the phenomena observed in the last two experiments is that the metal of the gauze conducts away the heat so rapidly that the gas on the side of the gauze opposite the flame is never raised to a temperature sufficiently high to light it.

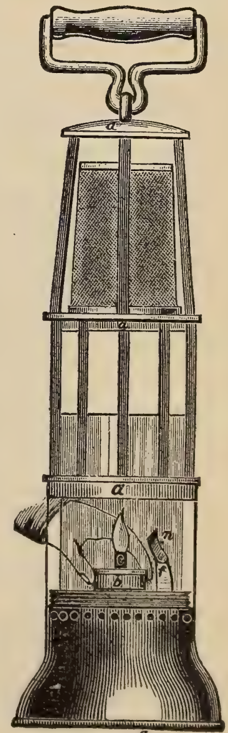


FIG. 181.

Advantage is taken of this principle in the construction of the Davy safety-lamp for miners who have to enter mines containing combustible gases. It consists of jacket of wire gauze enclosing a lamp. Fig. 181 shows the construction of one of these lamps.

3. Conductivity of Liquids.

Experiment 7.

Fill a test-tube nearly full of water and hold it in an inclined position, as shown in Fig. 182, so that the flame from a spirit lamp or Bunsen burner may strike the upper part of the tube just below the surface of the water.

FIG. 182.

1. Is the heat transferred rapidly or slowly to the lower part of the tube?

2. Is water a good or a bad conductor of heat?

The conductivity of liquids is, as a usual thing, much lower than that of solids.

Name some liquid which is an exception to this law.

4. Conductivity of Gases.

Air and other gases are poorer conductors of heat than liquids. The low conductivity of porous bodies, such as cloth, feathers, sand, etc., is in a great measure due to the air which they contain.

II.—Convection.

5. Mass-Transference of Heat.

Experiment 1.

Repeat Experiment 7 above, heating the tube at the bottom and holding it at the top.

1. How does your observation in this case differ from that in the above experiment?

2. How is the heat transferred from the lamp to the upper layers of the water?

To answer this question perform the following experiments:

Experiment 2.

Fill a small flask with boiling water which has been coloured with some aniline dye or ink, cork it, and, without inverting it, place it at the bottom of a pail filled with cold water. Remove the cork.

1. What takes place?

2. What is the reason?

To answer this question consider

(*a*) Which is the denser, the hot water placed at the bottom or the cold water surrounding it:

(*b*) According to the laws of buoyancy (Art. 17, page 105), should the pressure of the cold water cause the hot water to rise or to sink.

Experiment 3.

Repeat Experiment 2, introducing the mouth of the inverted flask just below the surface of the water and removing the cork with as little agitation of the cold water as possible.

1. How do your observations differ from those in the case of Experiment 2?

2. What is the reason for the difference in the phenomena?

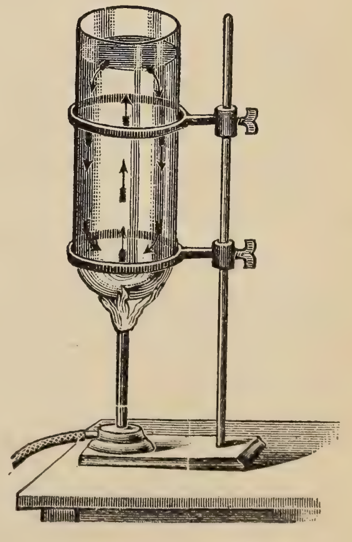


Fig. 183.

Experiment 4.

Fill a large beaker nearly full of water, add a few crystals of aniline dye or potassium

permanganate, and heat by applying the flame of a spirit lamp or Bunsen burner to the centre of the bottom of the beaker (Fig. 183).

1. Does the water in the upper part of the beaker become warmed?

2. If so, how has the heat been transferred from the lamp?

To answer this question observe the currents formed in the water.

Vary the experiment by applying the flame at other points of the beaker.

1. From what point do the upward currents always start?

2. Trace the directions of the return currents.

Currents set up in a fluid on account of the unequal temperature of its parts are called **convection currents,** and the transference of heat from one point to another by transferring the matter containing it is called **convection.**

6. Convection Currents in Liquids.

The above experiments illustrate the action of heat in producing convection currents in the mass of liquids. The following experiment shows how a continuous current may be kept up in tubes by the same action.

Experiment 5.

Arrange apparatus as shown in Fig. 184. The upper vessel A may be made by cutting the bottom from a bottle. B is a large flask and C and D glass tubes. The perforated corks should be rubber. Fill the apparatus with water, taking care that no air be left in the flask B. Place some aniline dye

in the upper vessel. Apply heat to the bottom of the flask B.

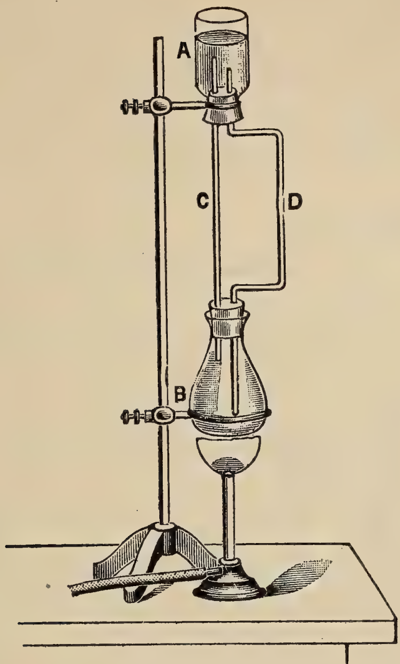


Fig. 184.

1. Describe the circulation of the water in the tubes and in the vessels.

2. Explain the reasons for this circulation.

3. What would happen if the tube C were pushed down and its lower end brought to the bottom of the flask B?

The distribution of heat throughout the mass of large bodies of water, such as ponds and lakes, is brought about mainly by convection currents.

In the autumn as the surface water gradually becomes colder and hence denser, it descends and the warmer water from below takes its place. This in turn becomes colder and descends. The exchange goes on until the temperature of the water at the surface falls below 4° C,

or the point of maximum density. Being then lighter than the warmer water below, the surface water remains at the top, and, when its temperature falls below the freezing point, ice forms and remains at the surface.

Why is the fact that water at 4° C. is denser than ice said to be "a wise provision in the economy of nature?"

7. Practical Applications.

By a circulation similiar to that illustrated in Experiment 5, buildings are heated by a system of hot water pipes. Fig. 185 shows the way in which the pipes are connected and the

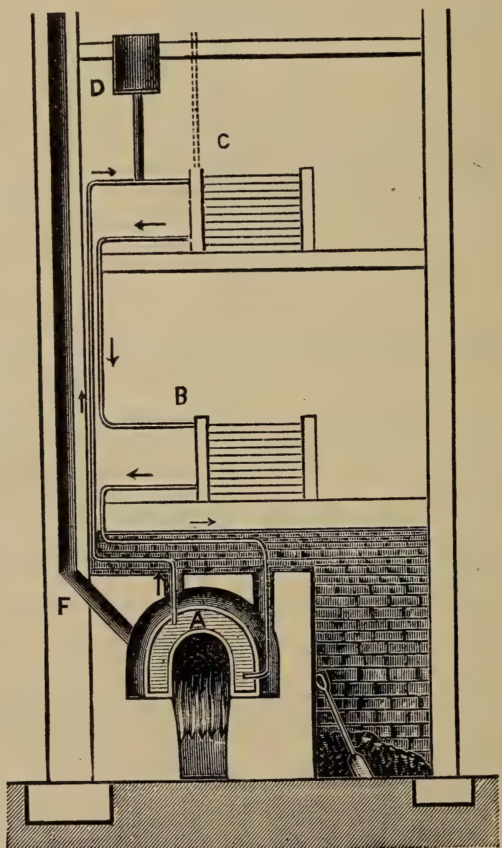


FIG 185.

direction of the circulation. The boiler A, filled with water, is heated by a furnace in the basement of the house. The upper part of the boiler is connected by means of a pipe with an expansion tank D, placed in the top of the building. Another pipe passes downward from the expansion tank through coils B and C in the rooms to be heated, and enters the boiler near its base.

8. Convection Currents in Gases.

Experiment 6.

Make some touch paper (paper that will burn without flame and give off a great quantity of smoke) by dipping paper in a saturated solution of potassium nitrate (saltpetre) and then drying it.

Light some of the paper and hold it above the flame of a candle, or better, above the chimney of a burning lamp.

1. What are the directions of the air currents which the smoke renders apparent?

2. What is the cause of these currents?

Experiment 7.

Make a wooden or metal box of the form shown in Fig. 186. The front should be a pane of glass which slides into its place through grooves. Cut two holes in the top of the box and over each hole place a lamp chimney. Remove the front, light a candle, place it under one of the chimneys in the position shown in figure, and replace the front. Light some touch paper and hold it over the other chimney.

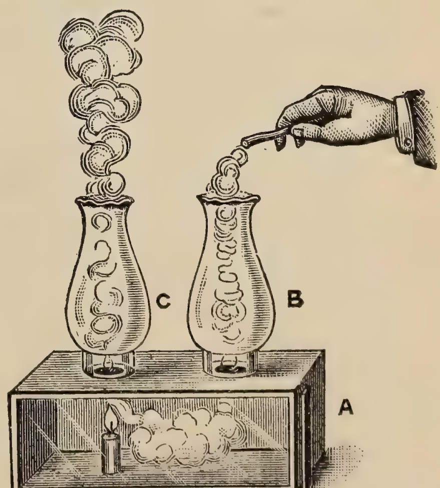


Fig. 186.

Describe and explain the currents of air observed.

Close the chimney B with your hand.

1. What happens after a short time?

2. Explain the reason.

Experiment 8.

Place a lighted candle in a large glass jar (a candy jar answers well), and insert a perforated cork into which glass tubes are placed in the positions shown in Fig. 187.

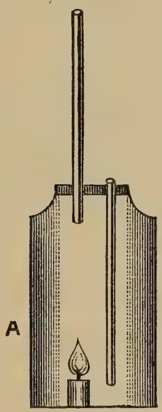


FIG. 187.

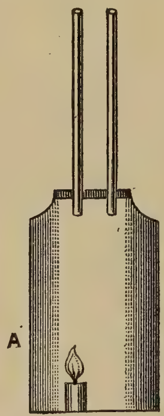


FIG. 188.

1. Does the candle continue to burn?

2. If so, explain how fresh air is supplied to it and how the products of combustion are removed from the jar.

Draw the right hand tube up to the position shown in Fig. 188.

Observe the burning of the candle for a short time.

What takes place? Explain the reason.

9. Ventilation.

Experiments 7 and 8 illustrate the modes of producing air currents, and show the necessity of providing a means of ingress as well as egress to any confined space in which the air is being vitiated. The air of dwelling houses is vitiated by the respiration of those living in them, and by the combustion of the oil or gas used for lighting. Means of removing the foul air and bringing in fresh air should be provided. The production of convection currents is the simplest expedient. This principle is taken advantage of in the heating and the ventilating of buildings by warm-air furnaces

Fig. 189 shows a system of heating and ventilating rooms in which a number of persons are required to remain for a considerable time. The air comes from the outside through the fresh air opening into the fresh air room, passes over the furnace, is heated, and

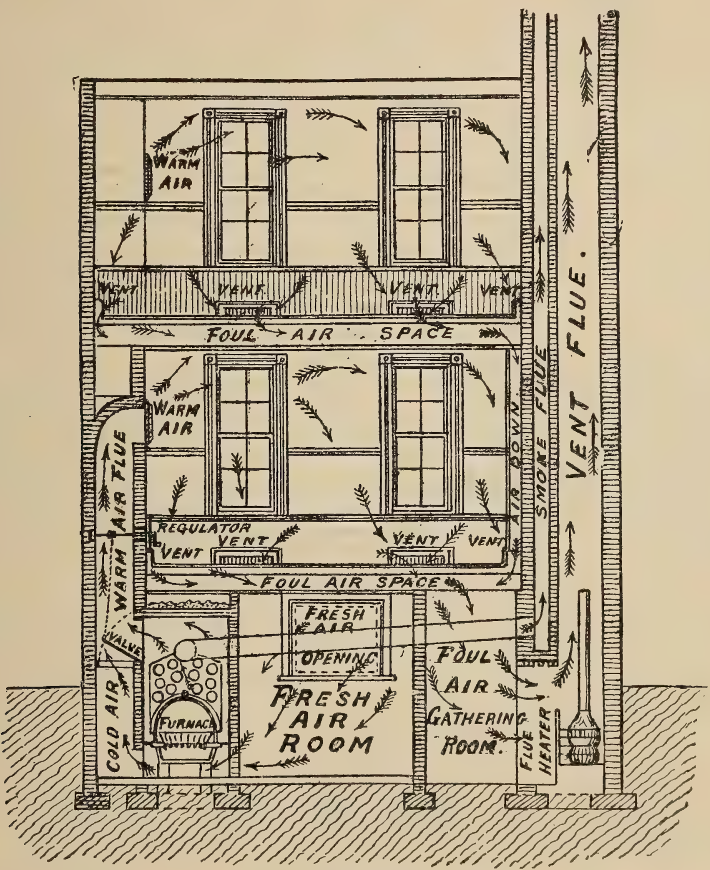


FIG. 189.

ascends through the warm air tube into the rooms. After circulating through a room and heating it, the air passes through vents in the wall into foul air spaces under the floor and down through a duct into the foul air gathering room. From this it is taken to the outside of

the building by a vent flue, in which an upward draught is maintained by means of the heat which it receives from the hot smoke flue placed alongside of it.

The air passages are so arranged that a part of the cold air from the fresh air room may pass through a valve directly into the warm air flue without passing over the furnace, the quantity of this air being regulated by a regulator connected with the valve. In this way the temperature at which the air enters the room is under control. In summer, when the furnace is not in use, the circulation, for the purpose of ventilation, is maintained by keeping the vent flue hot by means of a small stove or a flue heater kept burning at its base.

10. Convection Currents in Nature.

Winds are the result of convection. Different parts of the earth's surface become unequally heated, and air currents are consequently set up. Their directions depend mainly on the position of the heated belts and the rotation of the earth.

Ocean currents are to a certain extent the result of convection, but these are also influenced by the action of the prevailing winds.

III.—Radiation.

Experiment 1.

Heat an iron ball to a high temperature and place at a distance of a foot or two from it and on a level with it, the bulb of an air thermometer or one of the bulbs of a differential thermometer (Fig. 190).

1. What change in temperature does the thermometer indicate?

2. Is this change in temperature due to a change in the temperature of the surrounding air?

To answer this question interpose a screen of glass or tin between the ball and the thermometer.

What do you observe?

The heat is said to be transmitted from the hot ball to the thermometer by **Radiation.** In the same way heat is transmitted to bodies in a room from a hot stove or from an open fire, and from the sun to the earth. This transmission is independent of the air as it takes place in the most perfect vacuum we can produce. To explain the phenomena of radiation it is found necessary to suppose *that a medium, called ether, pervades all space and penetrates between the molecules of all ordinary matter, which are embedded in it and probably connected with one another by its means.*

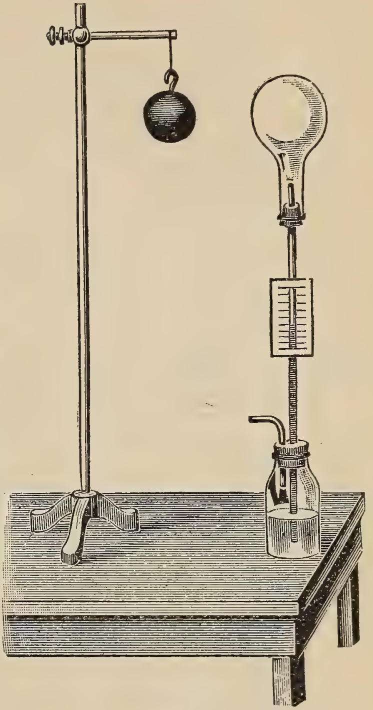


FIG. 190.

The vibrating molecules of a hot body communicate their motion to the ether which surrounds them, and thus cause vibrations to be set up in the ether. These vibrations by a species of wave-motion pass from the heated body in all directions through the ether, and may, on reaching any body of matter, communicate their energy to its molecules, and it in turn is heated.

The transmission of heat then by **radiation consists in the transformation of the energy of molecular vibration, or heat, into the energy of ether vibration, or radiant energy; and the transformation of radiant energy into heat.**

The first transformation is generally called **Emission,** the second **Absorption.**

11. The Emissive Power of a Body.

Our most common experiences teach us that the emissive power of a body—that is its power to transform heat into radiant energy—varies with its temperature. A hot stove radiates more heat than a cold one. But the emissive power does not depend on the temperature alone.

Experiment 2.

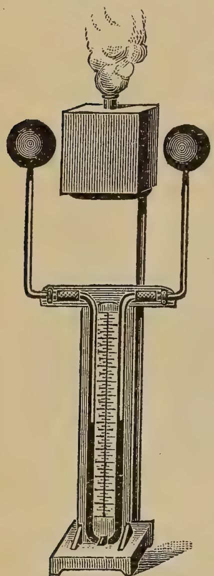


Fig. 191.

Blacken the bulbs of a differential thermometer by smoking them over a candle flame, turn them up as shown in Fig. 191. Blacken one of the faces of a cubical tin box about four or five inches wide, fill it with boiling water and place it midway between the bulbs, with the blackened surface facing one of the bulbs and the opposite bright surface facing the other bulb.

1. At what temperature is each of the surfaces of the cube?

2. Which bulb of the thermometer absorbs the more radiant energy?

3. Which surface, the blackened or the bright one, has the higher emissive power?

Repeat the experiment, roughening with sand-paper one of the surfaces, and leaving the opposite one polished.

Which has the higher emissive power, the polished surface or the roughened one?

Experiment 3.

Take two small tin cans of the same size furnished with lids, cut a hole in each lid through which a stirrer and a thermometer can be inserted. Blacken the outside of one and polish that of the other. Pour the same quantity of water heated to the same temperature (70° or 80° C.) into

each, and place them on some non-conducting material. Stir the water in each can at intervals and take the temperature.

1. Which can lose heat the more rapidly ?
2. Which has the higher emissive power ?

The emissive power of a body depends upon

1. **Its Temperature.**
2. **The Nature of its Surface.**

Dull, black surfaces have the highest emissive power and bright polished ones the lowest.

12. Absorptive Power.

Experiment 4.

Place an iron ball heated to a high temperature (Fig. 192) midway between the bulbs of a differential thermometer, one bulb of which is blackened, the other covered with tinfoil.

1. What change do you observe in the liquid levels ?
2. In which bulb is the more radiant energy transformed into heat ?

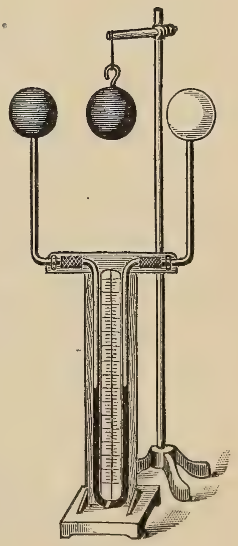


FIG. 192.

This experiment and others of the kind show that a body whose emissive power is high possesses great absorptive power, or that, as it is generally stated, **good radiators are good absorbers.**

13. Diathermancy of Transmissive Power.

Bodies which allow radiant energy to be transmitted through them without much increase in their temperatures are said to be diathermanous. Rock salt is one of the most diathermanous of solid bodies. Air is also fairly diathermanous, but water vapour is not.

1. How will the presence of water vapour in the air affect the quantity of the earth's heat changed into radiant energy during any particular interval?

2. When will the surface of the earth at any particular place cool the more rapidly, on a clear or on a cloudy evening? Why?

No body is perfectly diathermanous, nor is any body a perfect absorber. Most bodies exercise what is called selective absorption. For example, glass allows the radiant energy from a highly heated body, like the sun, to pass, but absorbs the radiant energy emitted by a red-hot ball or by an open fire.

14. Reflection of Radiant Energy.

Bright polished bodies are as a usual thing neither diathermanous nor good absorbers. The greater part of the radiant energy falling upon them is reflected from their surfaces and sent back into space without transformation. **Good reflectors are poor absorbers and good absorbers poor reflectors.**

Since there can be no loss of energy, the total amount of radiant energy falling on a body equals the amount reflected + the amount absorbed + the amount transmitted by the body.

Radiant energy becomes known to us not only by its transformation into heat, but also by its power of exciting the nerves of the eye and awakening the sensation of light. It is by means of radiant energy that we see objects.

QUESTIONS.

1. Why is it that if boiling water is poured into a thick glass tumbler it breaks, while if the water is poured into a thin glass vessel it does not break?

2. A piece of paper held in the flame of a lamp will burn, yet the paper may be held in the lamp flame without igniting if it is wrapped around a cylinder of brass. Explain. What would happen if a wooden cylinder were substituted for the brass one? Why?

3. If a copper kettle is filled with cold water and placed over a gas flame, the flame shrinks away from the kettle and does not come in contact with its bottom. Explain the reason.

4. Why is flannel a good substance of which to make clothes to keep our bodies warm, and also a good substance to wrap around a block of ice to keep it from melting?

5. Why are (*a*) ice houses constructed with double walls, (*b*) double windows used in houses in winter?

6. Why, in freezing ice cream, is the freezing mixture put in a wooden vessel and the cream in a metal one?

7. Water may be boiled in a paper box placed over a lamp flame without burning the paper. Explain the reason. Make the experiment. The paper pails used by oyster dealers will answer.

8. Formerly to ventilate a mine two shafts were provided at opposite ends of the mine and a fire kept burning at the bottom of one of the shafts. Explain the air currents set up.

9. What is the source of the heat given out by the Gulf Stream to the British Isles? Trace its transmission.

10. What effects are produced upon the climate of a place and upon the variations of temperature in it by the presence of a large body of water near it? Explain the reason.

11. Should a kettle intended to be heated by standing in front of a fire be bright or black? Give reasons for your answer.

12. The earth absorbs and radiates heat more quickly than the water. In what direction A or B (Fig. 193) will the air move (*a*) during the day, (*b*) during the night? Explain the cause of land and sea breezes.

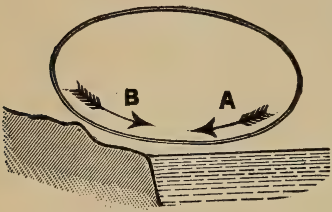


Fig. 193.

13. Should soot be allowed to collect on the bottom of a kettle used in heating water over a flame? Should the remaining part of the kettle be kept bright or dull? Give reasons.

14. Explain the advantages of silver-plating the outside of a calorimeter.

15. The bulbs of two identical thermometers are coated, the one with lamp black, the other with silver; compare their readings (*a*) when in a water bath, (*b*) when exposed to the direct rays of the sun, (*c*) when exposed on a clear night. Explain why they do not agree on all these occasions.

16. A Norwegian cooking box consists of a wooden box having a thick lining of felt inside, so arranged as to leave a central space into which the vessel containing the food is placed. The food is partially cooked, placed in the box, and covered over with the lid. Why will the cooking be completed in the box?

17. A building is heated with hot water pipes. Explain fully how the heat is transmitted from the furnace of the boiler to a person in the building. What would be the effect, on the temperature of some distant part of the building, of coating the pipes near the boiler with (*a*) woollen felt, (*b*) with dull blacklead?

CHAPTER XXI.

NATURE AND PROPAGATION OF LIGHT.

1. How we See Objects.

Experiment 1.

Take an unlighted candle into a darkened room.

Can you see the candle?

Can you see other objects in the room?

Light the candle.

Can you see the flame of the candle?

Are other objects in the room made visible by it?

Objects are seen by the **light** which is sent from them to the eye of the observer.

2. What is Light?

Since by this theory, and this only, the phenomena can be satisfactorily explained, *the external physical cause of the sensation of sight is believed to be ether-waves whose wave-lengths and vibration-frequencies lie within certain limits. These waves, which have their origin in some luminous body, are propagated in all directions; and, when transmitted to the retina of the eye, become stimuli of the optic nerve fibres, and give rise to the sensation of vision.*

Radiant energy which can affect the eye and produce vision is called Light.

As there are air-waves whose vibration-frequencies are either too slow or too rapid to affect the ear and produce the sensation of sound, so there are ether-waves whose vibration-frequencies are either too slow or too

rapid to affect the eye and produce vision. These, as we shall see, are capable of producing other effects.

The vibrations of the ether take place not in the direction of the wave, like the vibrations of the particles of the air in sound-waves, but in a plane at right angles to it. In this respect they resemble water-waves.

3. Luminous, Transparent, Translucent and Opaque Bodies.

Bodies from which light proceeds are said to be **luminous.** Those with which light originates are **self-luminous.** The sun, a lamp or gas flame, and the white-hot filament of an incandescent electric lamp are examples of self-luminous bodies.

The vibrating molecules of these bodies communicate their motion to the ether which surrounds them, and thus set up those ether-waves which have the power of exciting the optic nerves.

Bodies, like the moon, which are themselves non-luminous, become **illuminated** in the presence of self-luminous bodies by the light which they receive from those bodies and transmit by reflection.

Bodies which transmit the greater part of the light falling upon them, and through which objects can be distinctly seen, are said to be **transparent.** Those which transmit some light, but through which objects cannot be distinguished, are **translucent.** **Opaque** bodies are those which do not transmit light.

The terms transparent and opaque are relative. No body is perfectly transparent, and very thin layers of most bodies transmit more or less light.

Give examples of transparent, translucent and opaque bodies.

4. Rectilinear Propagation of Light.

Experiment 2.

Make a large pin-hole in each of three pieces of blackened cardboard.[1] Mount the pieces on blocks of wood as shown in Fig. 194, and so adjust them that a candle flame placed at A

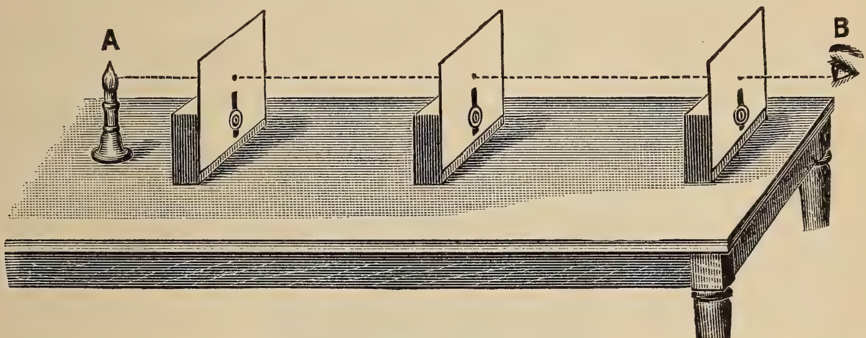


FIG. 194.

can be seen by an eye at B without disturbing the pieces of cardboard, pass a thread through the holes and stretch it.

Does the light in passing from the candle to the eye travel in a straight line?

Experiment 3.

Cut a hole about one centimetre in diameter in a piece of cardboard and mount the piece on a block of wood. Place a candle at a distance of about 10 cm. in front of one face of the cardboard and a movable white screen opposite the other face as shown in Fig. 195.

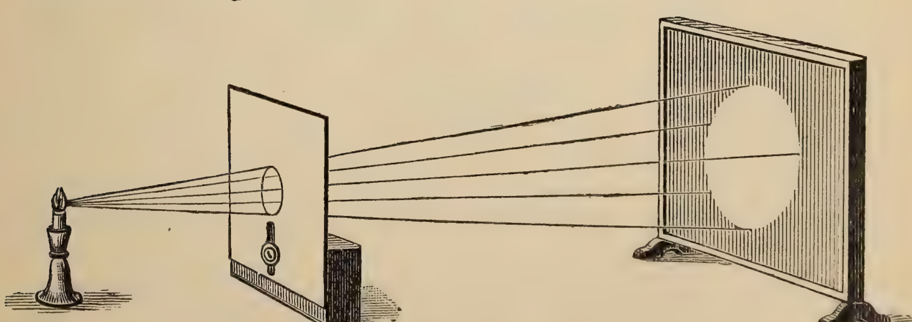


FIG. 195.

[1] For manual training exercise, see Appendix, page 330.

Move the screen backwards and forwards and note changes in the illuminated circle on the screen.

What evidence have you that light travels in straight lines ?

5. Ray, Pencil, and Beam of Light.

A **ray** is the line along which light is propagated.

A collection of rays from the same source is called a **beam**, when the rays are parallel (Fig. 196), and a **pencil**, when the rays are convergent (Fig. 197) or divergent (Fig. 198). The term pencil is used by some writers to denote any collection of rays from the same source, and a beam is defined as a parallel pencil.

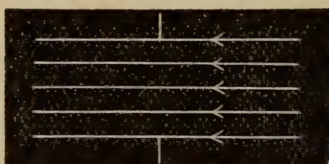


FIG. 196.

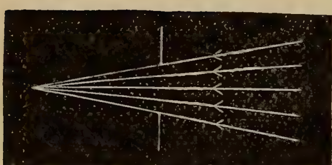


FIG. 197.

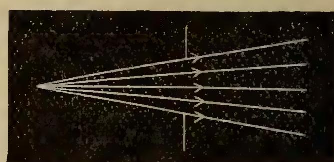


FIG. 198.

6. Images by Means of Small Apertures.

Experiment 4.

Make a hollow cylinder, about 6 inches in diameter, by rolling up a sheet of heavy cardboard. Place a lighted candle in a darkened room, and surround it with the cylinder. Prick a pin-hole in the cardboard on a line with the centre of the flame of the candle, and place in front of the hole and at a distance of three or four inches from it, a sheet of letter paper.

1. What is projected on the card ?
2. How is it formed, and why is it inverted ?

To answer this question consider :—

(*a*) That the flame is made up of an infinite number of luminous points from each of which rays of light are passing out in every direction.

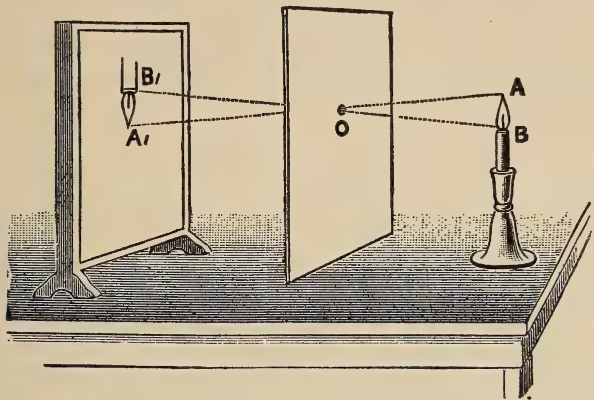


Fig. 199.

(*b*) That the light which passes from any one of these luminous points A, or B (Fig. 199) through the pin-hole travels in a straight line from the point to the hole, and continues to travel in the same direction after passing through the hole.

(*c*) That when a ray of light falls upon a screen an image of the luminous point from which it proceeds is formed on the screen.

Experiment 5.

On a bright day darken a room, make a hole about half an inch in diameter in one of the closed shutters, and place a white cardboard screen at a distance of two or three feet from the hole.

What is projected on the screen? Explain the reason.

QUESTIONS.

1. If you make a pin-hole in the bottom of a box, and replace the lid by a piece of tissue paper, you see on the paper images of external objects. Explain the formation and the character of these images.

2. When sunlight passes through the spaces between the leaves of trees, circular patches of light are seen on the ground. Why?

Are the circular patches made by openings in the leaves, which are circular? What shape would these patches have in case of a partial eclipse of the sun?

3. Why does the size of the image (Experiment 4) become larger as the screen is removed further from the pin-hole?

4. Why does the image become dimmer as it becomes larger?

7. Shadows.

Experiment 6.

Place a candle before the screen used in Experiment 3 and in the path of the light falling upon the screen place a small square of blackened cardboard or tin.

Observe the shadow on the screen.

Show by a diagram that the formation of the shadow is a direct result of the rectilinear propagation of light.

Move the card backward and forward.

Why does the size of the shadow projected on the screen change?

Are all parts of the shadow equally dark? If not, how do you account for the difference in the degree of darkness of the different parts of the shadow?

To answer the latter part of the last question, perform the experiment as follows:—

Experiment 7.

Arrange a gas burner or coal-oil lamp to give a large, flat, fan-shaped flame. Place a white paper screen about 16 inches square at a distance of 4 or 5 feet from the flame and parallel with it. Support a card 2 or 3 inches square between the flame and the screen in such a position that a shadow about two-thirds the size of the screen is cast on it (Fig. 200). You will observe that, as in the last experiment, the part of the shadow around the edges is much lighter than that nearer the centre. To understand the reason of this, prick a pin-hole

in the screen (1) in the darkest part near the centre, (2) on the line between the dark and the light parts of a shadow, (3) in the light part of the shadow, (4) in the illuminated part of the screen. Place the eye behind the screen at each pin-hole, and look at the flame through each hole.

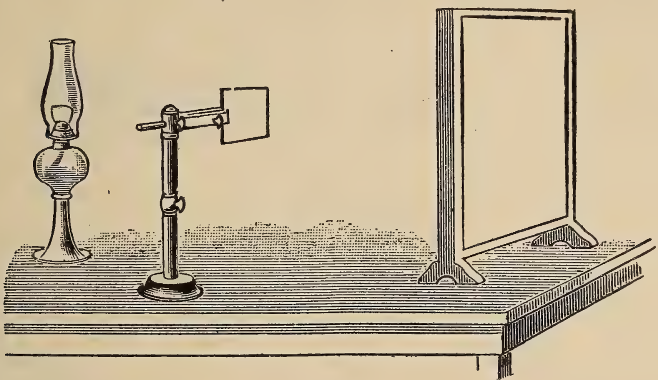


FIG. 200.

1. In which case can (1) the whole flame, (2) a part of the flame, (3) the edge of the flame, (4) no part of the flame, be seen?

2. How, therefore, do you account for the difference in the degree of darkness of the different parts of the shadow?

The dark portion of a shadow which receives no direct light from a luminous body is called the **umbra**.

The shadow around the umbra, which is lighter than it, because it is partially illuminated by direct light from a part of the luminous body, is called the **penumbra**.

FIG. 201.

Experiment 8.

Repeat Experiment 7, coating the lower part of the lamp chimney with black varnish and allowing the light to pass from the lamp to the screen through a small opening made by removing the varnish from a spot about 3 mm. in diameter (Fig. 201).

How does the penumbra in this case differ from that observed in Experiment 7?

What is the cause of the difference?

If the radiant were a luminous point there would be no penumbra (Fig. 202). The cone of light ACD, proceeding from the luminous point A, is totally stopped by

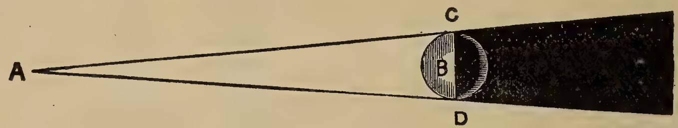


FIG. 202.

the opaque body B, and the portion of the diverging cone on the side of B opposite from A will be in shadow.

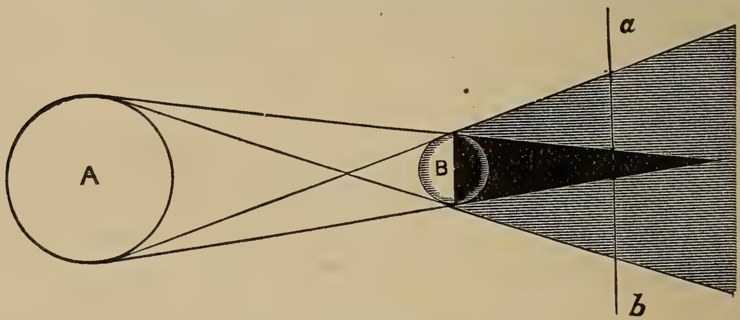


FIG. 203.

If the luminous body A is larger than the body B, the cones will be as shown in Fig. 203. A screen *a b* placed

FIG. 204.

behind B will be cut by both cones, and a shadow (Fig. 204) consisting of an umbra and a penumbra will be projected on it.

QUESTIONS.

1. Make a drawing similar to Fig. 203 to show the position of the umbral and the penumbral cones when the luminous body A is (1) smaller than B, (2) equal in volume to it.

2. If a pencil is held upright between a flat gas flame and a wall, the shadow is well-defined when the flame is "edge on," but not well-defined when it is "broadside on." Explain the reason. Try the experiment.

3. Why is the shadow of a body thrown by an electric arc lamp sharp and well-defined? Would a ground glass globe placed around the arc make a difference in the sharpness of the shadow? Explain.

4. By referring to Fig. 205 indicate the relative positions of the sun and moon in the case of

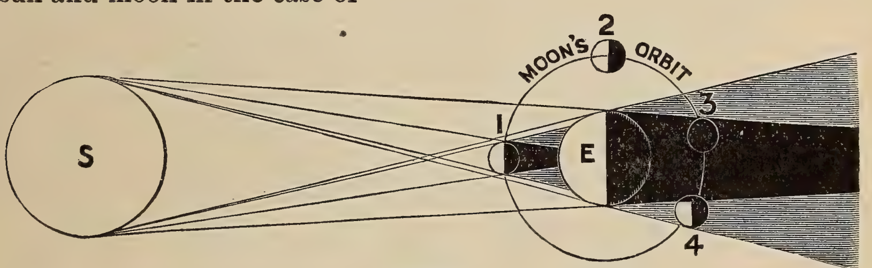


FIG. 205.

(*a*) a total eclipse of the sun,
(*b*) a partial eclipse of the sun,
(*c*) a total eclipse of the moon,
(*d*) a partial eclipse of the moon.

Is a person in the umbra or the penumbra of the shadow when he sees a partial eclipse of the sun?

5. When will the transverse section of an umbra of an opaque body be (1) larger than, (2) equal to, (3) smaller than, the body itself?

6. What is the shape of a section of the earth's umbra on the moon in an eclipse? What does this prove with regard to the shape of the earth? Explain.

CHAPTER XXII.

REFLECTION OF LIGHT.

We have learned (Art. 14, page 248) that the greater part of the radiant energy falling upon bright polished bodies is reflected from their surfaces. The reflection of light may be illustrated by the following experiments.

Experiment 1.

Through a small hole in a shutter admit a beam of sunlight into a darkened room and hold a mirror in its path (Fig. 206). Burn touch-paper,[1] or scatter crayon dust, in front of the

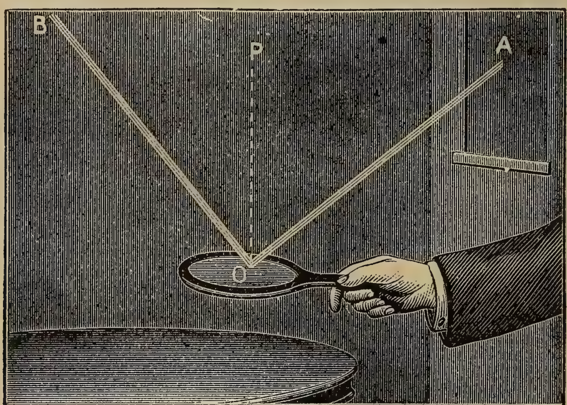


Fig. 206.

mirror and turn it so that the beam will fall upon it at different angles. Observe the changes in the direction of the reflected beam as the mirror is rotated.

The angle AOP which an incident ray makes with the normal to the reflecting surface is called the **angle of incidence,** and the angle POB which the reflected ray makes with this normal is called the **angle of reflection.**

[1]Prepared by dipping paper in a saturated solution of potassic nitrate.

1. Laws of Reflection.

Experiment 2.

Arrange apparatus[1] as shown in Fig. 207, the semi-circular board is about 24 inches in diameter and the circumference is graduated in degrees.

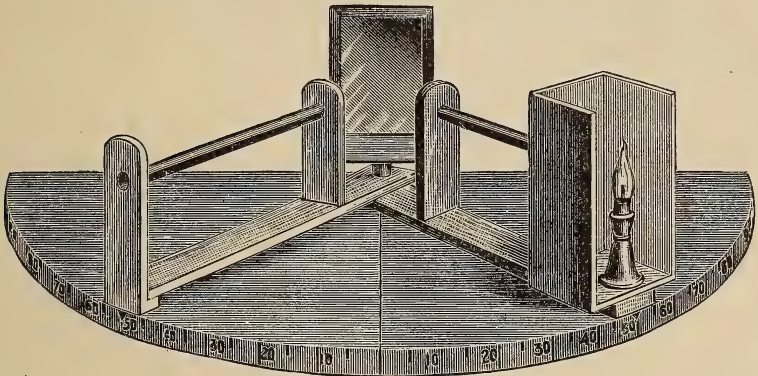


FIG. 207.

The movable arms are pivoted at the centre of the circle.

The tubes are about 3 mm. in diameter and are blackened on the outside. Whatever the position of the arms the tubes both point always to the same point on the mirror, which is supported at the centre of the circle with its reflecting surface perpendicular to the radius, drawn to the zero mark on the scale.

Give the arm carrying the candle a number of different positions, and for each position adjust the other arm, so that the light reaching the mirror through the one tube is reflected to the eye through the other.

1. What relation is found to exist between the angle of incidence and the angle of reflection ?

2. Describe the position of the plane in which the incident and the reflected rays lie.

---

[1]For manual training exercise, see Appendix, page 330.

The above experiments illustrate the following **laws of reflection.**

1. **The angle of reflection equals the angle of incidence.**

2. **The incident and the reflected rays are both in the same plane, which is perpendicular to the reflecting surface.**

Experiment 3.

Make the laboratory quite dark, and allow a beam of light to fall in succession upon (1) a mirror, (2) a pane of polished window glass, (3) a sheet of white unglazed cardboard, (4) a sheet of blackened cardboard.

1. In which cases is the light reflected in a definite direction and a distinct patch of light thrown on a screen placed in the path of the reflected rays? In which of these cases is the patch of light the brightest? Why?

2. In which of the cases is the reflecting surface seen with the greatest ease from all parts of the room? In which is it almost invisible? Why?

The total amount of radiant energy falling upon a body equals the amount reflected + the amount absorbed + the amount transmitted by the body (Art. 14, page 248).

The mirror reflected the greater part of the light falling upon it, and transmitted and absorbed but little. The surface of the mirror being smooth, the light was reflected in a definite way and a distinct image of the radiant was projected on the screen placed in the path of the reflected rays. Since an object is seen by the light which it reflects to the eye of the observer, the mirror cannot be seen unless the eye is in the direct path of the reflected rays.

The white cardboard also reflects most of the light falling upon it; but, as its surface is rough and the various parts of it are inclined at different angles, the light is reflected in different directions, and hence scattered or diffused (Fig. 208). Since the reflected light passes outward in all directions from the surface of this body, it can be easily seen from all points in front of its illuminated side.

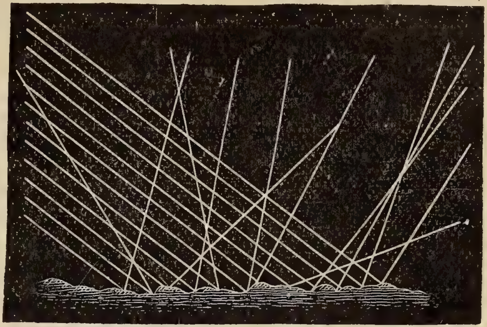


FIG. 208.

The window-glass transmits the greater part of the light falling upon it; but the part reflected by it is reflected, as in the case of the mirror, in a definite way, and an image of the radiant is seen on a screen placed in the path of the reflected rays. The glass is therefore not seen from points not in the line of these rays.

The blackened cardboard absorbs nearly all of the light, and, since it reflects but little, is almost invisible.

Experiment 4.

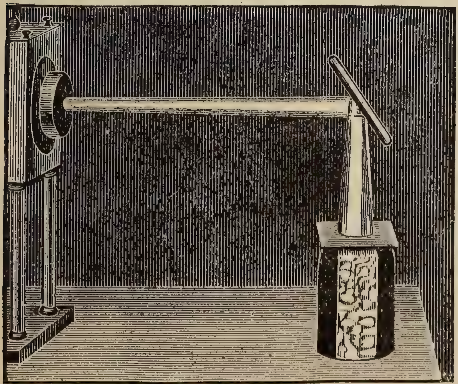


FIG. 209.

Take a glass jar 4 or 5 inches in diameter, fill it with water and cover it with a card which has a hole cut in it. Let a beam of light into a darkened room and reflect it with a hand mirror into the jar (Fig. 209). Add a teaspoonful of milk to the water.

1. Why was the water almost invisible, while the mixture, when the milk was added, fills the room with radiance?

2. Why does the smoke from touch-paper make the path of a beam of light visible?

2. Images from Plane Mirrors.

The formation of images by the reflection of light from plane mirrors is one of our most common observations.

The position of the image of a point, in relation to the mirror and the point itself, may be approximately determined by experiment in the following manner:—

Experiment 5.

Place a mirror MN (Fig. 210), which is at least 15 cm. long and 5 cm. wide, in a vertical position on a table with one of its longer edges horizontal. It can be held in this position by attaching it to a rectangular block of wood with two rubber bands. Stick a pin in the table at A, a point which is at a distance of about 15 cm. from the mirror. Also

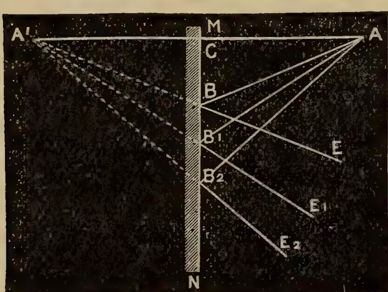


Fig. 210.

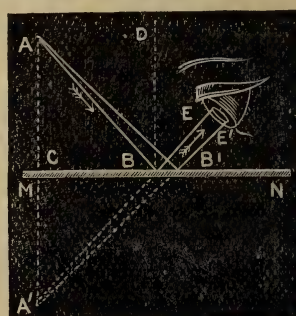


Fig. 211.

stick pins in the table in front of the mirror at any other points E, E_1, E_2, etc. Place the eye successively at E, E_1, E_2, and stick pins alongside the mirror at the points B, B_1, B_2, etc., B being in a straight line between E and the image of A as seen from E, and B_1, B_2 being in similar positions with respect to the image and E_1, E_2 respectively. Draw a line

AC, from A at right angles to the mirror, and join by lines the pins E and B, E_1 and B_1, E_2 and B_2. Now remove the mirror and produce the lines AC, EB, E_1B_1, E_2B_2 backward until they intersect.

If the experiment is performed with care the lines will all meet in a point A_1, the distance AC being equal to A_1C.

It should be noted that although the rays of light from the illuminated pin appear to come from the point A_1, the image of the pin, it is manifest that they **only appear** to come from this point, but the eye is affected in the same way as if the rays really did diverge from it and an image is seen. The image has no real existence, because the rays do not come from the other side of the mirror but reach the eye along the lines ABE, AB_1E_1, etc. (Figs. 210, 211.)

3. Image of a Luminous Object Formed by a Plane Mirror.

The image of a luminous object is made up of the images of the infinite number of luminous points which compose it; but when the positions of the images of a limited number of these points are found, the form and the position of the image of the object can usually be determined.

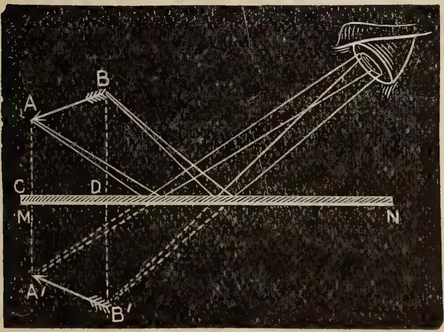


FIG. 212.

For example, when the positions of the images of the points A and B of the object AB (Fig. 212) are determined by the method given in Art. 2 above, the position of the image A_1B_1 is determined.

4. Lateral Inversion.

Experiment 6.

Stand before a mirror and hold up your right hand.

Which hand is held up by the image behind the mirror?

Place a printed page in front of a mirror.

What peculiarity do you observe in the image of the print? How do you account for this?

To assist you in answering the last part of the last question, draw the image formed by a plane mirror of the letter L, by the method given in Art. 3 above, finding the positions of the images of the two extremities and the angular point.

CHAPTER XXIII.

REFRACTION AND DISPERSION OF LIGHT.

1. How is the Direction of a Beam of Light affected when it Passes from a Medium of one Density into a Medium of another Density?

Experiment 1.

Through a small opening in a shutter admit a beam of sunlight into a darkened room and direct it so that it will fall obliquely on the surface of water contained in a large glass jar (Fig. 213). To make the path of the light in the water

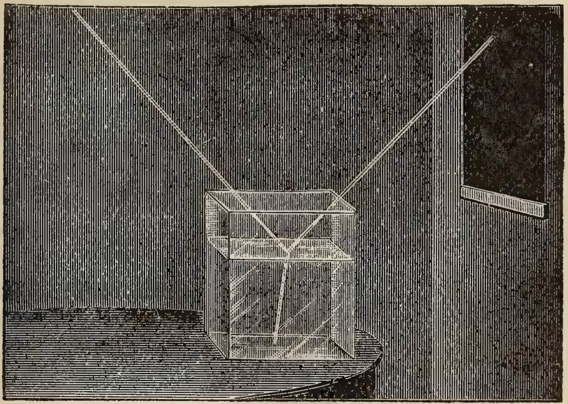


Fig. 213.

visible add a drop or two of milk or a little soap solution, and to make it visible in the air burn touch-paper or scatter a little crayon dust in the air surrounding the jar.

Observe the change in direction of the beam at the point where it enters the water.

Experiment 2.

Adjust a candle so that the light from it will pass over the upper edge of a rectangular tank and illuminate the whole of the opposite end, leaving the bottom of the tank

wholly in the shadow cast by the end of the tank nearest the candle (Fig. 214). Now fill the tank with water.

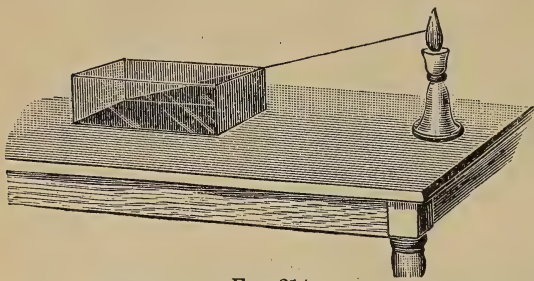


Fig. 214.

Does the shadow still cover the whole bottom? If not, how do you account for the change in the illumination?

The change in direction which takes place in rays of light in passing obliquely from a medium of one density to a medium of a different density, for example, from the air to the water in the tank, **is called refraction.**

In passing from one medium into another of greater density the rays are bent towards the perpendicular to the surface separating the two media, and in passing into a medium of less density they are bent away from the perpendicular.

2. Effects Produced by Refraction.

Experiment 3.

Draw a line with red ink on a sheet of white paper and place a rectangular bottle filled with water over a portion of the line (Fig. 215). View the line obliquely from above.

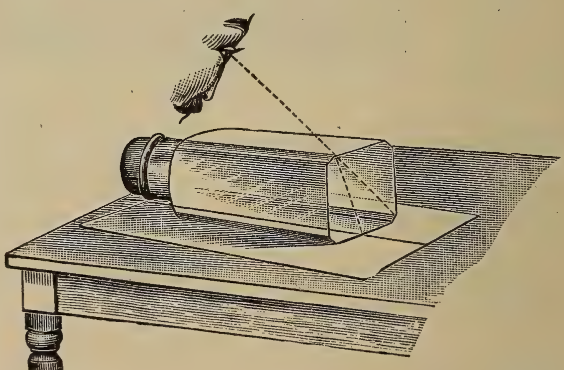


Fig. 215.

Describe and account for the change in the appearance of the line.

Experiment 4.

Drop a small coin into a cup and place the eye in such a position that it is just hidden by the edge of the cup. Keeping the relative positions of the cup and the eye unaltered, pour water into the cup.

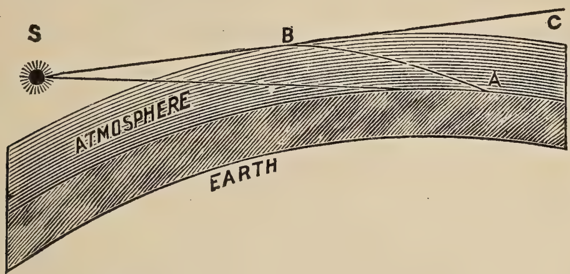


FIG. 216.

Explain why the coin is now visible, and make a drawing to show the directions of the rays by which it is seen.

The sun is visible to us in the evening when it is in reality below the horizon; because the light which comes from it is refracted in passing into and through the atmosphere, which increases in density as it nears the surface of the earth. Fig. 216 shows the direction of the rays by which it is seen.

Experiment 5.

Plunge a straight stick obliquely into water.

1. What apparent change in the direction of the stick takes place at the point where it enters the water?

2. Make a drawing showing the directions of the rays by which the submerged part is seen.

3. Explain, by means of a diagram, why objects under water appear nearer the surface than they are in reality.

3. Refraction of Light by a Lens.

Experiment 6.

Hold a double convex lens (a burning glass or a reading glass answers well) in such a position that the sun's rays will pass through it and fall upon a piece of paper. Move the lens backwards and forwards and note how the size of the illuminated area is affected by changes in the distance of the lens from the paper. Scatter some crayon dust in the path of the rays of light falling upon the lens.

1. Make a diagram to show how the lens disposes of the light which falls upon it.

2. What is the distance of the lens from the paper when the illuminated area is the smallest possible.

The point where the sun's rays meet after passing through a lens is called the **focus** of the lens, and the distance between the focus and the centre of the lens is called the **focal length.**

4. Images formed by a Lens.

Experiment. 7

Stand a candle, a convex lens, and a cardboard screen on a table in the order shown in Fig. 217 their centres being in the same horizontal line.

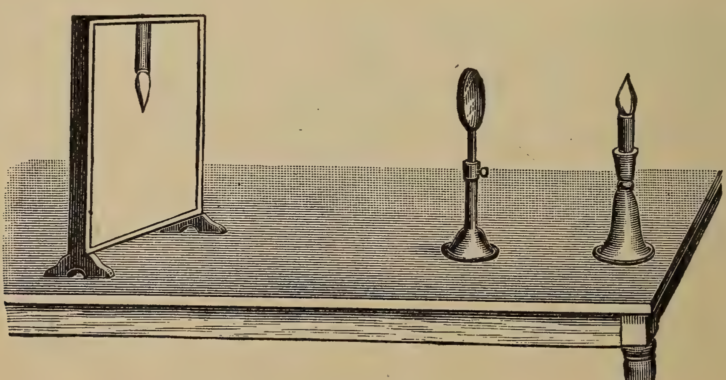


FIG. 217.

Place the candle at more than twice the focal distance from the lens. Move the screen backward or forward until a sharply defined image of the candle is formed on it.

1. Is the image larger or smaller than the candle? Is there any relation between the relative sizes of the candle and the image and their relative distances from the lens?

2. Is the image erect or inverted?

Move the candle gradually toward the lens, adjusting the screen as before.

1. What changes takes place in the position and the size of the image?

2. Where is the image when the candle is at twice the principal focal distance? Where, when it is at the focus of the lens?

3. Where is the image when the candle is between the principal focus and the lens? To answer this question, place the eye on the side of the lens opposite to the candle and look through the lens at the candle.

5. Simple Microscope.

Experiment 8.

Hold the convex lens over a printed page at a distance from it less than the focal distance.

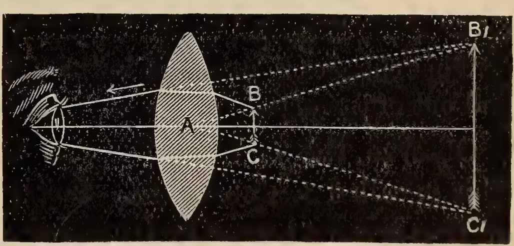


FIG. 218.

Describe the effect of the lens on the appearance of the print?

Since the image formed by a convex lens when the object is placed between the focus and the lens is erect and enlarged, a lens of this class may be used as a simple microscope for magnifying objects placed on the side of the lens opposite the eye. Fig. 218 shows the relative positions of the eye, the object BC, and its image B_1C_1.

6. Refraction of Light by a Prism—Dispersion.

Experiment 9.

Through a narrow slit in a shutter admit a beam of sunlight into a darkened room, and in the path of the beam place a triangular glass prism, of the form shown in Fig. 219, turning it around until the light passes through it. Place a screen so that the rays transmitted by the prism fall perpendicularly upon it.

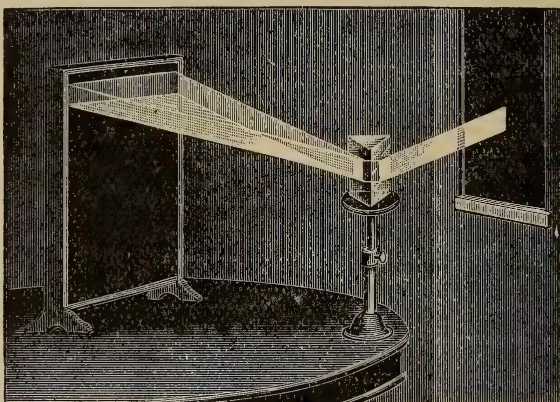


FIG. 219.

What changes in direction in the light takes place in passing into and out of the prism?

Observe the continuous band of colours on the screen. This is called **a spectrum.** Observe how one colour shades off into the next, passing from red at one end to violet at the other, through all the gradations of orange, yellow, green and blue.

We can account for the effect observed only on the following suppositions:—

1. *That white light is composite, not simple.*

2. *That the rays of which it is composed differ in refrangibility, and consequently are separated by being transmitted through the prism.*

3. *That rays of different degrees of refrangibility give rise, when falling on the retina of the eye, to different colour sensations, the least refrangible being red and the most refrangible violet.*

7. Upon What Does the Colour of Objects Depend ?

Experiment 10.

Again project a spectrum on the screen. Hold over the slit in succession pieces of glass of different colours, red, green, blue, etc.

Do the glasses give colour to the light, or do they quench some of the colours existing in the light ? How do you know ?

To answer more fully the latter part of this question, perform the following experiment.

Experiment 11.

Pass a red ribbon through the spectrum near the prism.

What colour is it in the red, in the green, and in the blue parts of the spectrum respectively ?

Repeat the experiment, using (1) a white ribbon, (2) a green one, and (3) a black one.

Experiment 12.

Procure strips of white, red, green, and blue paper, each of which should be about 3 cm. long and 2 mm. wide, and paste them apart on a sheet of black cardboard several times larger than the strips. View each strip in order, beginning with the white one, placed in a strong light, through a glass prism, holding its edges parallel to the length of the strip.

Describe the appearance of each strip as seen through the prism.

These experiments show that **colour does not originate with the body which is said to possess it, but that it is due to the light not quenched, or absorbed, by the body.**

A body is red, because it absorbs all the rays of the white light falling upon it except those with which the

sensation of red originates; it is blue, when it absorbs all the rays except thoes with which this sensation originates, and so on. A body is black when it absorbs all light rays.

What is a white body?

The character of the unabsorbed rays determines the colour of a body.

The colour of a body, therefore, depends on—

1. **Its molecular structure.** Different bodies on account of difference in molecular structure absorb different classes of rays, and hence differ in colour.

2. **The nature of the light which falls upon it.** The blue ribbon placed in a red light appeared black, because the red rays were absorbed by the body which absorbs all rays except blue. For similar reasons any changes whatever in the light produce corresponding changes in the shades of colour of objects viewed by it. Bodies do not appear to have exactly the same colour in the evening as at noon-day, because the evening sunlight does not contain as much of the violet end of the spectrum as the noon sunlight, a larger proportion of the violet rays being absorbed in travelling a longer distance through the air.

A transparent body is colourless when it absorbs no light, or absorbs the various classes of rays in equal proportions. If it absorbs more of one class of rays than of another its colour is conditioned upon the transmitted rays. The colour of opaque bodies is due to the unabsorbed light reflected by them.

QUESTIONS.

1. Sunlight is entering a darkened room through a very narrow vertical crack in the shutter. An observer who can see the crack distinctly looks at it through a prism with its edge vertical. Describe what he sees and indicate in a figure the path of the rays to his eyes.

2. A lamp flame, looked at through a glass prism, appears to be coloured blue on one side and red on the other. Draw a picture tracing the rays from the lamp to the eye, and showing which side of the coloured image is red, and which side is blue.

3. Explain the origin of colour when white light passes through a solution of copper sulphate, and trace the effect of varying the thickness traversed.

4. One piece of glass appears dark green when held up to the light, and a second piece appears dark red; explain why, when they are put together, no light passes through them.

5. A ribbon purchased by gas-light appeared to match the dress with which it was to be worn. Next morning the match appeared to be very imperfect. Explain this.

6. Light enters a room through blue glass; what appearance does a red coat present in such a room?

7. Why are sunsets characterized by red and yellow tints?

CHAPTER XXIV.

MAGNETISM.

I.—Polarity.

1. Natural and Artificial Magnets.

Experiment 1.

Procure a piece of the mineral magnetite (Fe_3O_4), hammer it out so that it is three or four times as long as broad, plunge it into iron filings, and lift it out (Fig. 220).

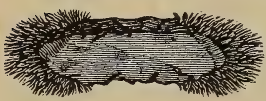


FIG. 220.

Describe what you observe.

Experiment 2.

Suspend the mineral by means of a wire stirrup and silk fibre, as shown in Fig. 221.

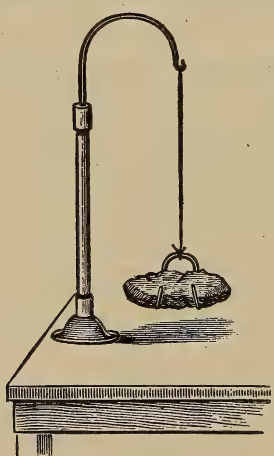


FIG. 221.

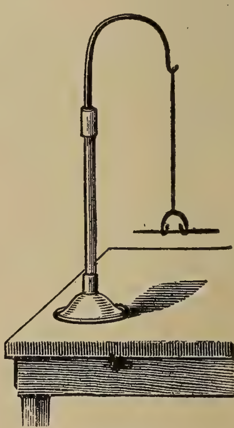


FIG. 222.

1. In what direction does it set itself? Twist it around a little way and let it go.

2. Does it after oscillation again set itself in the same direction?

Experiment 3.

Stroke repeatedly a piece of knitting-needle from end to end in one direction with the magnetite. Now repeat Experiments 1 and 2 above, using the needle instead of the magnetite. In suspending the needle a stirrup made of very fine wire should be used (Fig. 222).

How do the results compare with those observed in Experiments 1 and 2?

A body, like the magnetite or the needle rubbed with it, which possesses the property of attracting small masses of iron to itself and of setting itself, when poised, in a definite direction pointing north and south, is called a **magnet.**

The magnetite is called a **natural magnet,** because it usually possesses magnetic properties when taken from the earth. The term **lodestone** (leading-stone) was applied to it on account of the use made of it in navigation.

A steel bar or needle which has acquired the characteristic properties of a magnet is sometimes called an **artificial magnet.** The steel is said to be **magnetized,** and the process by which it has acquired its magnetic properties is called **magnetization.**

2. The Poles of a Magnet.

It is observed in the above experiments that the iron filings cling to a magnet in two separate tufts, one near each end, thus showing that the maximum attractive power is situated at these two points. The points are called the **poles** of the magnet, and the magnet itself is said to possess **polarity.**

The filings disappear all around the magnet midway between the poles, showing that at this line there is no attraction. This is called the **neutral line,** or the **equator** of the magnet.

An imaginary line joining the poles is call the **axis** of the magnet.

The pole which turns toward the north is called the **north-seeking** pole; and that which turns toward the south, the **south-seeking** pole.

3. Two Kinds of Magnetic Poles.

Experiment 4.

Magnetize two needles, as described in Experiment 3 above, and suspend one by a fibre. Take the other magnetized needle in your hand, and hold first one end and then the other near the N-seeking pole of the suspended needle.

1. What results do you observe?

Repeat the experiment with the S-seeking pole of the magnetic needle.

2. What evidence have you that there are two kinds of magnetic poles?

4. Laws of Magnetic Attraction and Repulsion.

Experiment 5.

Suspend both the magnetic needles used in the last experiment and place them (1) so that the N-seeking pole of the one shall be near the N-seeking pole of the other; (2) that the S-seeking pole of the one shall be near the S-seeking pole of the other; (3) that the S-seeking pole of the one shall be near the N-seeking pole of the other.

What attractions or repulsions are observed?

This experiment verifies the following law, which is generally known as the First Law of Magnetism :—

Law I.—**Like magnetic poles repel each other, and unlike poles attract each other.**

To verify the second law with any degree of accuracy, expensive instruments are necessary. The law may be stated thus :—

Law II.—**The force exerted between two magnetic poles, whether attraction or repulsion, is directly proportional to the product of their strengths, and inversely proportional to the square of the distance between them.**

5. Magnetic Bodies and Magnets.

A **magnetic body** is any body, like iron, capable of being magnetized. A magnetic body which is not magnetized may be readily distinguished from a magnet in the following manner :—

Experiment 6.

Take one of the suspended magnetic needles, used in Experiment 4 above, and bring first to one of its poles and then to the other (1) the end of a needle that has been magnetized, (2) any part of an unmagnetized needle.

What difference do you observe in the actions of the magnetic needle in the two cases?

If the end of a body repels one of the poles of a magnetic needle it is a magnet; if it attracts both poles of a magnetic needle it is magnetic.

Several of the metals are magnetic, but only nickel and cobalt, in addition to iron, possess magnetic properties in any marked degree.

6. Neutralization of Poles.

Experiment 7.

Suspend a screw, or other small piece of iron, from one pole of a magnet (Fig. 223), and move along over this, as shown in

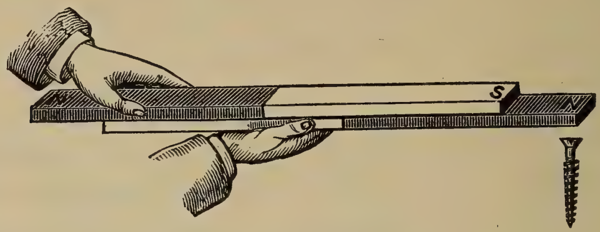


Fig. 223.

the figure, another magnet of the same size and of equal power, with the opposite pole towards the screw.

What happens when the two poles are near each other?

Experiment 8.

Place the two magnets used in the last experiment end to end with opposite poles together, as shown in Fig. 224. Now

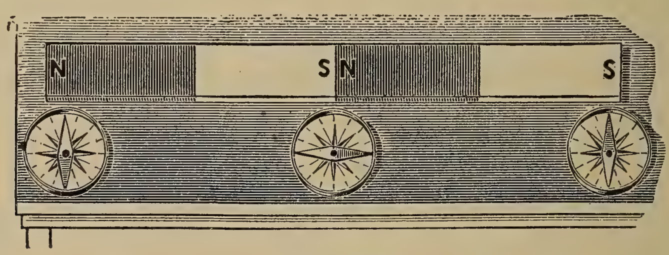


Fig. 224.

pass a suspended, or poised[1], magnetic needle around the combined magnets.

What evidence have you that there is now no pole at the line where the two magnets join?

[1] A cheap form of compass answers well for all such experiments.

Experiment 9.

Magnetize a piece of watch spring which is about 10 cm. long. Test the strength of its poles by lifting tacks with it. Now bend the spring until the two ends are in contact.

Does the ring thus formed show polarity at any point?

When the opposite poles of two magnets, or of the same magnet, are placed together, they tend to neutralize each other.

7. The Two Poles of a Magnet Inseparable.

Experiment 10.

Magnetize a knitting-needle, roll it in iron filings, and notice the positions of the poles. Break the needle into halves, and roll each half in the filings. Continue the process until the needle has been broken into small pieces.

1. What evidence have you that the two poles of a magnet are inseparable?

2. Are the poles of each separate piece of the needle different, that is, is one pole a N-seeking and the other a S-seeking pole?

To answer this question present each end of one of the pieces to the N-seeking or the S-seeking pole of a suspended magnetic needle.

3. If this process of breaking up these magnets were continued what would be the ultimate portion of the iron which would be likely to show polarity?

Place together the broken ends of two halves which have been separated, and each of which consequently possesses two poles.

Do the adjacent poles neutralize each other, leaving poles only at the ends?

A magnet cannot possess one pole only. Two poles, one N-seeking and the other S-seeking, co-exist in every magnet.

The co-existence of two poles in even the smallest part of a magnet is usually explained on the *theory that the molecules of a magnetic body possess polarity.*

II.—Magnetic Induction.

8. Phenomena of Induction.

Experiment 1.

Place a piece of soft iron with one of its ends near the pole of a magnet, as shown in Fig. 225, and bring a tack, or other small piece of iron, to the other end of the soft iron.

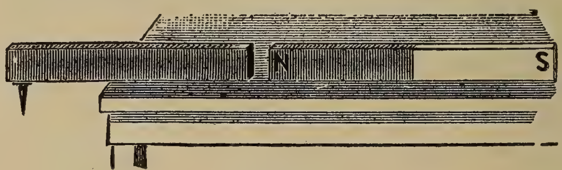


FIG. 225.

What do you observe?

Remove the magnet.

1. What takes place?

2. What properties did the soft iron possess when near the magnet?

3. Did it permanently retain these properties?

Experiment 2.

Place the soft iron again in the same position near the magnet, and bring a suspended magnetic needle near the end of the soft iron which is the more remote from the magnet, as shown in Fig. 226.

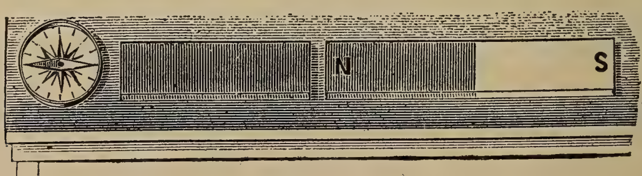


FIG. 226.

1. What is the pole at one end of the soft iron when the other end is near (1) the N-seeking pole, (2) the S-seeking pole of the magnet?

This magnetizing action of the magnet upon the soft iron placed close to it is known as **induction. Under induction, a magnetic pole induces opposite polarity in the end of a rod of soft iron nearest it, and similar polarity in the end farthest from it.**

How can you explain the phenomena of induction on the theory of the polarity of the molecules?

Experiment 3.

Repeat Experiment 2 above, placing two or more small soft iron rods between the magnet and the magnetic needle.

Does induction take place through a series of iron rods?

9. Induction Precedes Attraction.

Experiment 4.

Place a strong magnet on a table with its N-seeking pole projecting over the edge. Bring a tack to this pole of the magnet, add others to this in the form of a chain, as shown in Fig. 227.

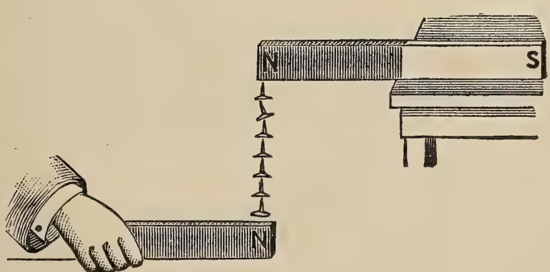


FIG. 227.

1. Explain why any one tack is held to the one above it.

2. What happens when (1) the N-seeking pole, (2) the S-seeking pole of another magnet is brought near the lowest tack? Why?

A piece of unmagnetized iron is drawn to the pole of a magnet because the pole induces opposite polarity in the end of the unmagnetized iron nearest it, and these unlike poles attract each other.

10. Method of Magnetization.

We have found (Art. 1, page 277) that a piece of steel when stroked in one way with the pole of a permanent magnet becomes itself a magnet. This is owing to the inductive action of the permanent magnet. The steel is found to be more difficult to magnetize in this way than the soft iron, but unlike the soft iron, which possesses magnetic properties only while under the direct influence of the inducing magnet, it retains its polarity after the magnet is removed.

11. Retentivity.

The retentivity, or the power to resist demagnetization, is very small in soft iron and very great in hard steel; but even in steel a certain amount of power is lost in time if the steel is subjected to any molecular disturbance. This loss may be prevented to a great extent by the use

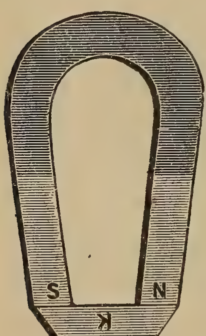


FIG. 228.

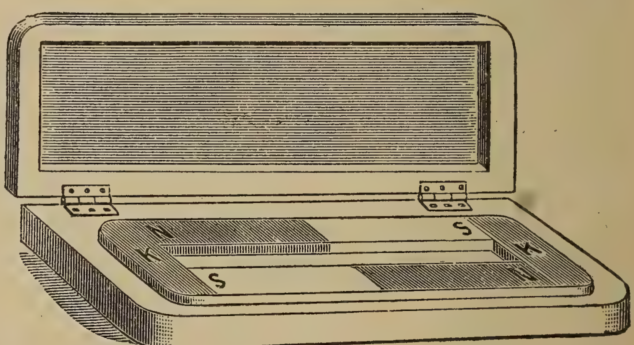


FIG. 229.

of "keepers." These are pieces of soft iron, which are used to join the poles of the magnet when not in use. Each pole of the magnet induces the opposite kind of polarity in the end of the keeper in contact with it, and these opposite poles attract each other and tend to preserve the arrangement of the molecules necessary for magnetization.

Fig. 228 shows a horse-shoe magnet with its keeper, and Fig. 229 indicates how keepers may be applied to bar-magnets.

12. Permeability.

Experiment 5.

Interpose between a magnet and an iron tack, (1) a sheet of cardboard, (2) a pane of glass, (3) a thin wooden board, (4) a thick iron plate.

1. Does the magnet attract the tack through each of these bodies?

III.—The Earth's Magnetism.

13. The Earth a Magnet.

We have observed in our various experiments that a magnetic needle suspended freely turns always in a definite direction when not influenced by any magnetic substance near it. We can account for this on the *theory that the earth is a magnet, and that the needle always tends to set itself in obedience to the laws of magnetic attraction when two magnets are brought near each other.* See Art. 4, page 279.

14. Declination of the Magnetic Needle.

The magnetic poles of the earth are not coincident with the geographical poles, and hence a suspended magnetic needle does not point exactly north and south. **The angle between the true north and south line and the direction of a compass needle is called the declination of the**

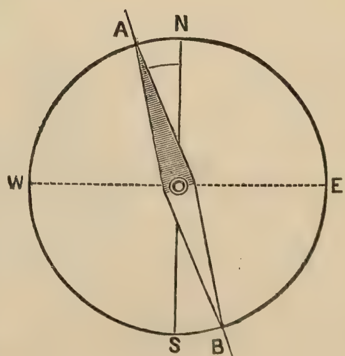


FIG. 230.

compass (Fig. 230). The angle varies in different places, and in the same place is subject to diurnal, annual and other periodic, as well as irregular, variations.

15. Inclination, or Dip, of the Magnetic Needle.

Experiment 1.

Magnetize a needle and suspend it by a silk fibre tied around it in such a position that it will rest horizontally.

Bring the needle over the neutral line of a bar-magnet and notice the position (Fig. 231). Gradually move it towards (1) the N-seeking pole, (2) the S-seeking pole. Describe the change.

How does the needle set itself in the various positions?

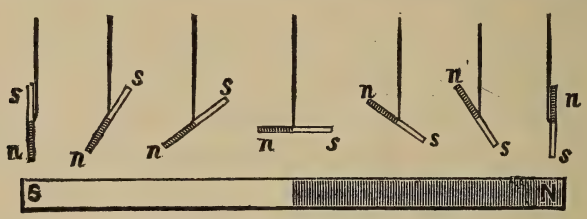


FIG. 231

Experiment 2.

Thrust a knitting-needle and a darning-needle at right angles to each other through a small cork. Using the darning-needle as an axis, mount the needles as shown in Fig. 232,

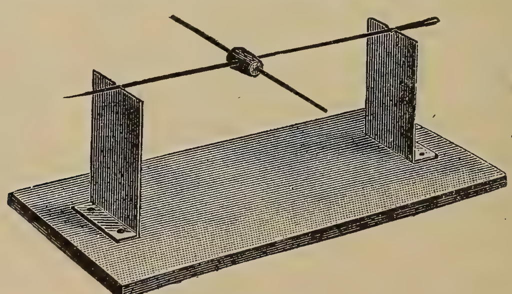


FIG. 232.

and adjust the knitting-needle in the cork so that it will remain at rest in a horizontal position. Magnetize the knitting-

needle with a strong magnet and place it again on the supports turning it in a north and south direction with the N-seeking pole pointing to the north.

1. Describe what takes place.

2. What is the cause of the change in the behaviour of the needle?

Experiment 3.

To answer the above question make a model of the earth in clay, embedding in it a bar-magnet in the position shown in Fig. 233. Repeat Experiment 1, using the model instead of the bar-magnet.

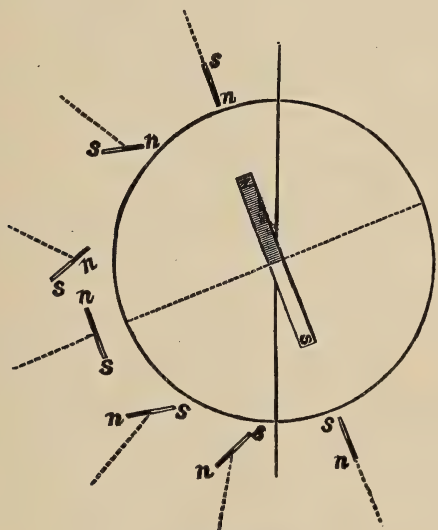


FIG. 233.

How does the suspended needle behave as it is carried around the ball of clay?

A freely suspended needle behaves in respect to the earth much in the same way as the needle carried around the ball of clay in the above experiment. At all points it has a tendency in accordance with the laws of magnetic attraction and repulsion to dip or point

towards the nearest pole. The magnetic poles are not points on the earth's surface but are down within its crust. The north magnetic pole is situated under Boothia Felix (Lat. 70° 5′ N and Long. 96° 46′ W). The south magnet pole has not been located, but it is probably near latitude 75° S and longitude 150° E.

The angle between the horizontal and the magnetic axis of a needle which is freely suspended about its centre of gravity is called the inclination, or dip, of the needle.

1. Is there any line on the earth's surface where the needle will remain approximately horizontal? If so where?

2. What change will take place in the dip of the needle as it is carried (1) toward the north pole, (2) toward the equator, (3) from the equator toward the south pole?

3. What is the position of the needle at each of the magnetic poles?

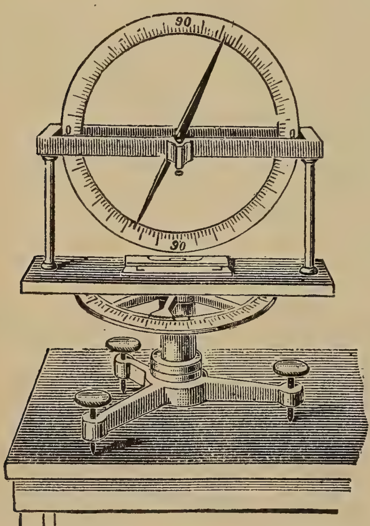


FIG. 234.

The needle used in Experiment 7 if carefully mounted will indicate roughly the inclination, or dip of the needle. To determine the angle with accuracy a specially constructed **dipping-needle** is used.

Its construction is shown in Fig. 234.

The needle is placed in the magnetic meridian, levelled, and the angle of inclination read from the graduated circle placed around it.

16. Mariner's Compass.

The mariner's compass consists of a permanent magnet on which is mounted a graduated card, the magnet being so poised on a pivot that the card and magnet remain always horizontal.

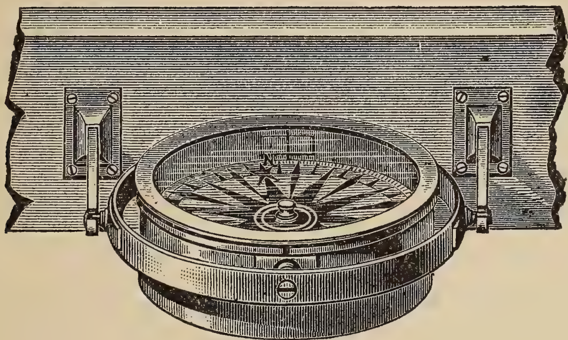


FIG. 235.

Fig. 235 shows a common form of the instrument.

Inside the compass-box is marked a vertical black line called the **lubber line.** The compass is so placed that this line is in the axis of the ship and indicates always the direction of the keel. The point of the compass at the lubber line, therefore, shows at any moment the direction in which the ship is moving at the time.

QUESTIONS.

1. You are provided with a steel sewing needle and are required to magnetize it so that its point may be a South-seeking pole. How will you do it?

2. You are doubtful whether a steel rod is neutral, or is slightly magnetized; how could you determine its magnetic condition by trying its action upon a compass-needle?

3. Six magnetized sewing-needles are thrust through six pieces of cork, and are then made to float near together on water with

their N-seeking poles upward. What will be the effect of holding (1) the S-seeking pole, (2) the N-seeking pole, of a magnet above them? Try the experiment.

4. Arrange three bar-magnets of equal strength so that there is no magnetic effect on a neighbouring magnetic needle.

5. Two similar rods of very soft iron have each of them a long thread fastened to one end, by which they hang vertically side by side. On bringing near the iron rods, from below, one pole of a strong bar-magnet, the rods separate from each other. Explain.

6. A horse-shoe magnet is placed near a compass-needle so as to pull the needle a little way round. On laying a piece of soft iron across the poles of the horse-shoe magnet, the compass-needle moves back toward its natural position. Explain this.

7. A piece of soft iron, placed in contact with both poles of a horse-shoe magnet at the same time, is held on with more than twice the force with which it would be held if it were in contact with only one pole of the same magnet. Why is this?

8. Where on the earth's surface does the N-seeking pole of a magnetic needle point in a generally southerly direction?

9. What is meant by saying that the magnetic dip at London is 67° 30′? State in general terms at what places on the earth's surface the magnetic dip is least.

10. A bar of very soft iron is set vertically. How will its upper and its lower ends respectively affect a compass-needle? Would the result be the same at all points on the earth's surface as at this latitude? If not, state generally how it would differ at different places.

CHAPTER XXV.

THE ELECTRIC CURRENT.

1. An Electric Current.

Experiment 1.

Take a strip of zinc about 10 cm. long and 3 cm. wide and connect it with a strip of copper the same size by means of a wire[1] about 50 cm. or more in length. Fill a tumbler about two-thirds full of water acidulated with about one-twelfth the quantity of sulphuric acid. Place the zinc and copper strips in the acidulated water, not allowing them to touch, and stretch the wire connecting them in a north and south direction (1) over, (2) under a compass-needle (Fig. 236).

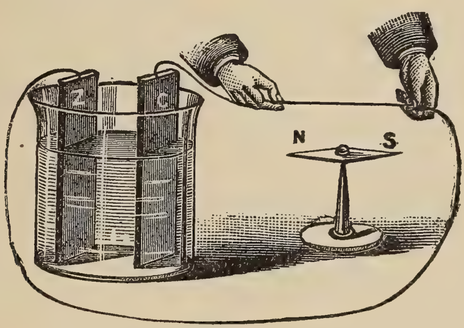


Fig. 236.

1. What change takes place in the direction of the needle when the wire is placed (1) over, (2) under the needle?

2. Does this change take place when the wire is above or below the needle, and the strips are removed from the liquid?

The wire evidently possesses new properties when the strips at its terminals are placed in the dilute acid.

---

[1] Copper magnet wire No. 20 will be found most convenient for making ordinary connections.

The **new properties of the wire** are said to be due to a **current of electricity, which passes through the wire.**

In using the term current, it must not be supposed that we know for a certainty that something is in reality flowing through the wire which is said to conduct the current. On account of the analogy of the conditions and effects to those of fluids flowing in pipes, the terms applied to this form of energy are those commonly applied to currents.

By the work which the so-called current will do, we recognize the presence of energy, but we are in ignorance of its nature. No theory regarding it is as yet universally accepted by scientists.

2. Simple Voltaic Cell.

Experiment 1, page 291, illustrates one common method of producing an electric current. We shall now repeat the experiment, examining more carefully the **conditions accompanying the generation of the current.**

Condition 1—An electric circuit.

Experiment 2.

Immerse the strips in the dilute acid, as in the above experiment, connect a wire to one plate, and, carrying it in a north and south direction over a magnetic needle, bring it near but do not let it touch the other plate.

Is the needle affected?

Now touch the wire to the other plate.

1. What change in the behaviour of the needle is observed? What does the change indicate?

This experiment indicates that a necessary condition of the flow of an electric current is a **complete circuit.** This circuit comprises the entire path traversed by the current, including the zinc and copper plates, the liquid between them, and the conducting wire which connects them.

The current is regarded as flowing from the surface of the zinc through the liquid to the copper plate, and from it through the external conductor back to the zinc (Fig. 237).

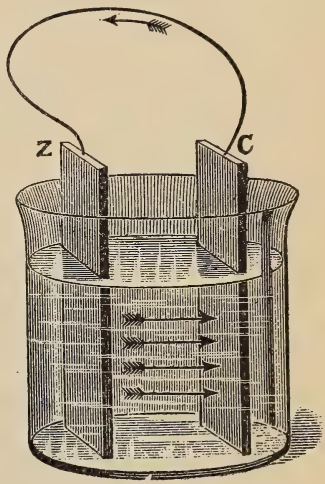


FIG. 237.

The portion of the zinc plate immersed in the dilute acid is called the **positive plate**, and the portion of the other plate immersed, the **negative plate**.

The portions of the plates outside of the liquid to which the ends of the external conductor are attached are called the **poles** of the cell, the external portion of the negative plate being the **positive pole**, and that of the positive plate the **negative pole**

When the poles are joined by a conductor (Fig. 239), the cell is said to be on a **closed circuit**; when they are not (Fig. 238), it is on an **open circuit.**

Condition 2—Physical and chemical actions in the cell.

Experiment 3.

Place the strip of zinc used in Experiment 1, page 291, in the dilute sulphuric acid, and observe its surface for a few minutes.

1. What change takes place in the appearance of the surface of the zinc in the acid?

2. What is the gas given off? (See High School Chemistry, Revised Edition, page 28.)

Place the copper strip also in the dilute acid and hold it parallel with the zinc and near it, but not touching it (Fig. 238).

1. Does the presence of the copper in any way affect the phenomena observed before?

2. Does any change take place in the appearance of the surface of the copper?

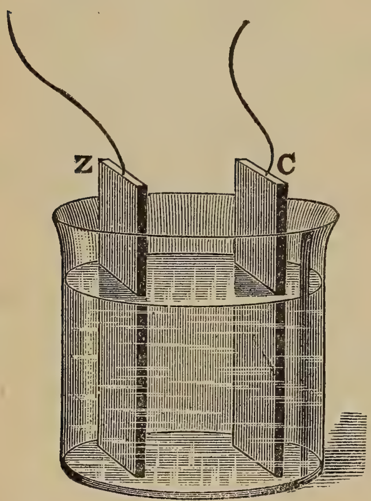


FIG. 238.

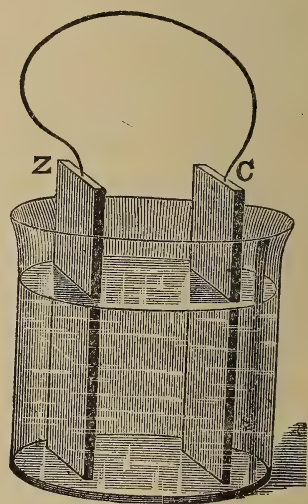


FIG. 239.

Connect the upper ends of the strips by a copper wire, or touch them together (Fig 239).

1. What is now observed at the surface of the copper?

2. Is there any change at the surface of the zinc?

3. Is the zinc being acted upon chemically? To answer this question, weigh the strip, place it in the acid, connect it with the copper, let it stand for a few minutes and weigh it again.

This experiment shows that the production of the electric current in the wire connecting the plates is accompanied by **chemical action.**

The zinc displaces the hydrogen of the acid, forming zinc sulphate, which dissolves in the water; and the liberated hydrogen appears at the surface of the copper plate.

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

The arrangement described above is one form of a **simple voltaic cell, or element.**

The essential parts of any voltaic cell are two different conducting plates immersed in a conducting liquid which acts chemically upon one of them, or if upon both, upon them with unequal power.

In all forms of cells in practical use the plate upon which the liquid acts most powerfully is zinc, and the other plate is usually either copper or carbon, carbon being most frequently used.

3. The Electric Current and the Chemical Action in the Cell.

While the production of an electric current by a voltaic cell is always accompanied by chemical action in the cell, no satisfactory evidence is found to show that the electric current is the result of the chemical action, or that the chemical action is the result of the current. All that can be said is that the one accompanies the other, and that, since the zinc enters into chemical combination, there is a transformation between the energy which produces chemical affinity and the energy of the electric current.

4. To Detect the Presence and the Direction of an Electric Current—The Galvanoscope.

Experiment 4.

Repeat Experiment 1, page 291, holding the connecting wire over the needle in such a way that the current passes (1) from north to south, (2) from south to north.

1. From your observations fill up the proper word, **east** or **west**, in the following rules for determining the direction of a current in a wire :

If a wire is stretched north and south above a magnetic needle and a current is passing from north to south, the N-seeking pole is carried toward the ; but, if it is passing from south to north, the N-seeking pole is deflected toward the .

2. Does the same rule apply if the wire is stretched below the magnetic needle ? Try.

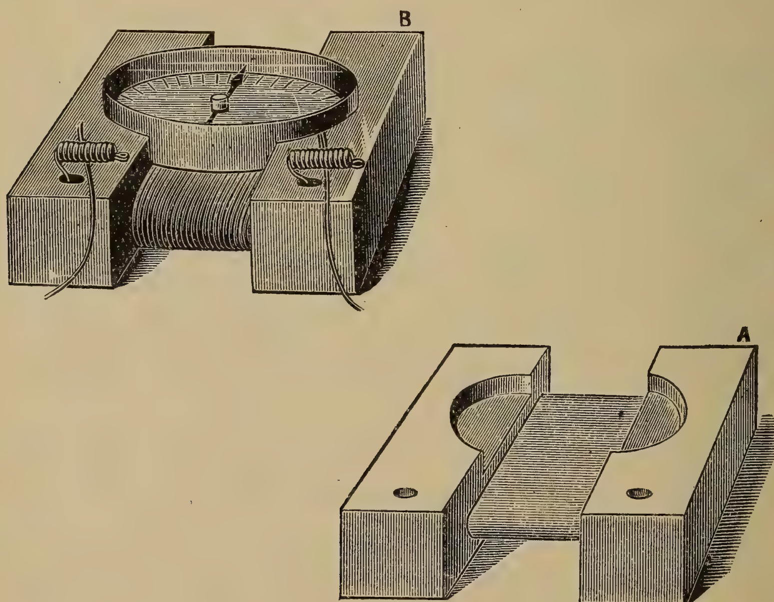


Fig. 240.

A feeble current flowing in a single wire either over or under a magnetic needle is unable to deflect the

needle; but if the wire is wound into a coil, and the current made to pass several times in the same direction either over or under the needle, it may be deflected. Such an arrangement for detecting the presence of a current is called a **galvanoscope.**

5. To Construct a Galvanoscope.

To make a galvanoscope of the form shown in Fig. 240, procure a small compass (the same will answer for the experiments in magnetism), and cut from a piece of board, about three-quarters of an inch thick, a spool of the form A with a recess for holding the compass. The size of the spool will of course depend on the size of the compass used. Fill the spool up to the compass by winding evenly around it cotton or silk-covered magnet wire. Wire of any number between 24 and 30 will answer. Connect the ends of the wire with binding posts. If these are not available, a good substitute may be provided by making a close coil of spring wire as shown in the figure. The coils are fastened to the ends of the wire and secured to the wood with tacks or screws. Holes about one-half inch in diameter should be bored in the spool, as shown, to serve as mercury cups for making rapid connections. Each of these is connected with the corresponding binding post by an iron wire.

When in use the instrument must be so placed that the coils of wire are parallel with the magnetic meridian.

6. Causes of the Weakening of the Current in a Voltaic Cell—Local Action and Polarization.

Experiment 5.

Obtain, if possible, a piece of chemically pure zinc. Immerse it in dilute sulphuric acid. Also immerse in the acid a piece of ordinary commercial zinc.

What difference is observed in the chemical action between the acid and the two pieces of zinc?

Experiment 6.

Amalgamate a piece of commercial zinc by first dipping it in dilute sulphuric acid to clean it, dropping a few drops of mercury on it, and spreading the mercury over its surface by rubbing with a rag or brush.

Immerse the amalgamated zinc in dilute sulphuric acid.

1. Is there any chemical action between the zinc and the acid?

2. Can the amalgamated zinc be used with copper to form a zinc-copper cell?

To answer this question, connect it and a copper plate with the galvanoscope, and partially immerse the plates in dilute sulphuric acid.

1. Does the galvanoscope indicate a current?

2. Does the hydrogen appear as usual at the copper plate?

3. Does the zinc waste away (1) when not connected with the copper plate, (2) when connected with the copper plate? Find out by weighing.

The fact that the commercial zinc wastes away in the dilute sulphuric acid, while the pure zinc and the amalgamated zinc do not, is explained on the theory that local currents are set up between the zinc and its impurities in electrical contact with it. The zinc then enters into combination with the acid when unconnected with any other plate.

Since a plate of ordinary zinc wastes away in a cell even when unconnected with any other plate without any useful work being done, a plate of amalgamated zinc is commonly used for this purpose. When the zinc is amalgamated the mercury dissolves the pure zinc on the surface, forming a clean uniform layer of pasty zinc

amalgam, and the zinc is acted upon by the acid only when it is connected by a conductor with another plate. As the zinc of the amalgam then combines with the acid, the mercury takes up more of the zinc, and the impurities float out into the fluid. Thus a homogeneous surface remains always exposed to the acid.

Why is chemically pure zinc not used in cells instead of amalgamated plates?

Experiment 7.

Connect the plates of a zinc-copper cell with the galvanoscope, allow the cell to stand for a few minutes and observe the changes in (1) the appearance of the surface of the copper, (2) the deflection of the needle of the galvanoscope.

1. What evidence have you that the strength of the current becomes weaker the longer the cell stands?

2. What change in the appearance of the copper plate accompanies the weakening of the current?

3. Is there any connection between the change at the surface of the copper plate and the weakening of the current?

To answer this question agitate the liquid in the cell with a glass rod rubbing all bubbles of gas from the surface of the copper plate.

Is the strength of the current increased?

Voltaic cells differ from one another mainly in the remedies provided to prevent polarization. The method most commonly employed is the use in the cell of some substance that will combine with the hydrogen, and thus prevent its appearance on the negative plate. This is usually an oxidizing agent, such as bichromate of potassium, nitric acid or manganese dioxide.

7. To Make a Bichromate Cell.

Fig. 241 shows how a simple form of cell, with which the greater number of the effects of the electric current can be shown, can be constructed at an expense of a few cents. Z is a zinc rod, such as is used in Leclanché's cell. It may be obtained from the telephone company, or from any dealer in electrical supplies. C, C are two electric light carbons. Z and C, C are inserted firmly into a short bar of wood and connected by wires as shown in the figure. The fluid may be prepared by dissolving 2 oz. of potassic bichromate in a pint of water and adding carefully 2 ozs. by weight of sulphuric acid. The zinc should be kept amalgamated, and the plates should be removed from the fluid when not in use.

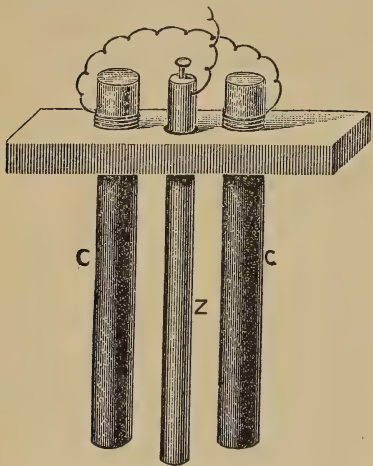


FIG. 241.

For many experiments a single voltaic cell does not give sufficient power.

A series of several cells constitute a **battery.** For all the experiments in this book, except that of producing an arc light (Experiment 3, page 321), a battery of two or three of the

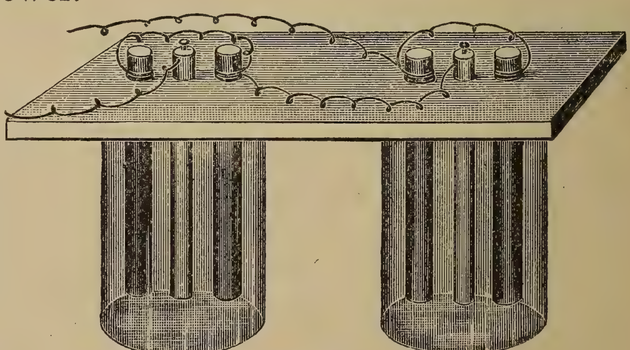


FIG. 242.

cells described above will be found sufficient. Fig. 242 shows how these cells may be combined to form a battery, the same piece of wood being used to support the plates of two or more cells. Note that the positive pole of one cell is connected with the negative pole of the next.

8. Conductors and Non-Conductors.

Experiment 8.

Arrange a voltaic cell as in Experiment 1, page 291, and connect the wires with the binding posts, as shown in Fig. 243, placing in the circuit at A (1) a few feet of fine

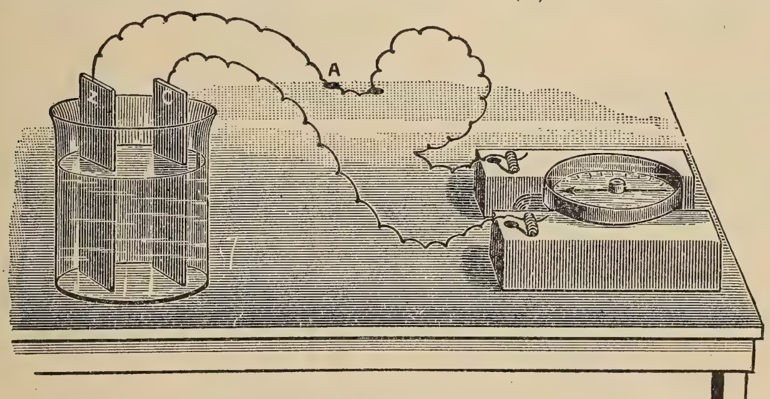


FIG. 243.

iron wire, (2) the same length of copper wire of the same size, (3) a string of the same length and about the same size, (4) a short wooden rod, (5) a glass rod or tube. Observe the deflection of the needle of the galvanoscope in each case.

In which case is the angle of deflection the greatest? In which cases is the needle not deflected?

The results observed in the above experiment are explained *on the theory that bodies differ in their power to conduct electricity, or in the resistance which they offer to the flow of the current.* When a body is a good conductor of electricity, it offers less resistance to the current than a poor conductor of equal cross-section and

length, hence a stronger current flows through it, and the needle of the galvanoscope is consequently deflected through a greater angle.

The following table gives a list of some of the more common substances classified according to their conductivities:

Good Conductors.	Partial Conductors.	Non-Conductors.
Silver.	The body.	Oil.
Copper.	Cotton.	Porcelain.
Gold.	Dry wood.	Wool.
Aluminium.	Marble.	Silk.
Zinc.	Paper.	Resin.
Platinum.		Guttapercha.
Iron.		Shellac.
Tin.		Ebonite.
Lead.		Paraffin.
Mercury.		Glass.
Charcoal.		Air.
Acidulated water.		

Bodies are usually divided into **good conductors, bad** or **partial conductors,** and **non-conductors**; but the distinctions are but relative. Even the best conductor offers some resistance to an electric current, while a weak current of electricity may be made to pass through any so-called non-conductor if a sufficient difference in potential is produced.

A non-conductor used for preventing a current from flowing from one conductor to another is called an **insulator.**

QUESTIONS.

1. You have a voltaic cell containing a plate of platinum and a plate of zinc immersed in dilute sulphuric acid. What occurs in the liquid when the two metals are united? Does anything occur that you can actually see? If so, what?

2. A steel fork and a steel knife are connected by wires with a galvanoscope. The knife and fork are used to cut a juicy and well-salted beefsteak, what will be the effect upon the galvanoscope? What will be the effect when a silver fork is substituted for the steel one, the steel knife being retained? Why?

3. Place silver on the tongue, and zinc under it, so that the two pieces touch. What occurs? Why?

4. Procure a metal cartridge shell (those used in shot-guns are suitable) and twist tightly around it one end of a copper wire. Fold the middle of a narrow strip of clean zinc over a small bar of wood and support the zinc inside the shell as shown in Fig. 244,

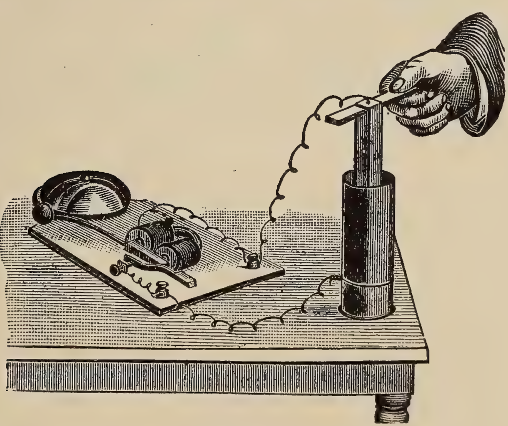


FIG. 244.

being careful that the zinc does not touch the metal of the shell at any point. Attach one end of another copper wire to the zinc, and connect the free ends of the two wires to the binding posts of an electric bell. Nearly fill the shell with dilute sulphuric acid.

What takes place? Explain the reason.

CHAPTER XXVI.

THE EFFECTS OF THE ELECTRIC CURRENT.

I.—Chemical Effects.

1. Electrolysis.

Experiment 1.

Connect by means of copper wires, as shown in Fig. 245 (1) one pole of a battery with a strip of platinum, (2) the other pole with one of the binding posts of a galvanoscope, (3) the other binding post of the galvanoscope with another strip of platinum.

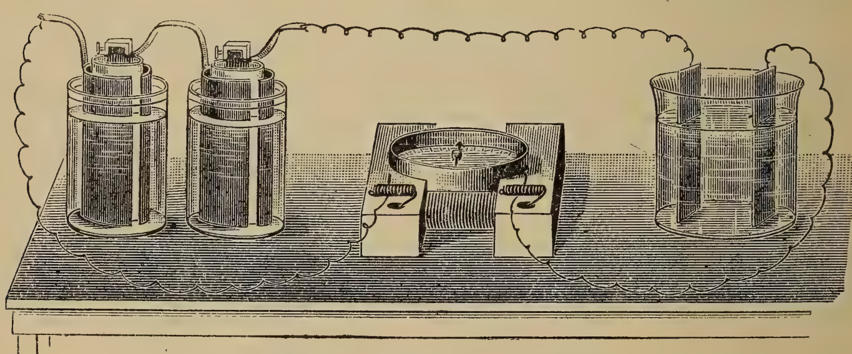


FIG. 245.

Keep the strips from touching each other and dip them into (1) mercury, (2) turpentine, (3) a solution of potassic iodide (KI) to which has been added a little starch paste to serve as a test for iodine (iodine turns starch a deep blue colour).

Observe the deflections of the needle of the galvanoscope, and the appearance of the liquids near the platinum strips.

1. In which cases is the current conducted by the liquids?

2. In which does a chemical change take place in the liquid conveying the current? What is the nature of that change?

3. Where are the substances resulting from the chemical changes liberated?

This experiment shows that with regard to their power of conducting an electric current there are three classes of liquids:

1. Those which, like mercury and molten metals, are conductors, but which are not decomposed by the current.

2. Those, such as turpentine, oils, etc., which are non-conductors.

3. Those which conduct an electric current and are decomposed by it. Such liquids are known as **electrolytes.** The plates by which the current enters and leaves the electrolyte are called **electrodes.** That which leads the current into the electrolyte is called the **positive electrode,** or **anode,** and that which leads it out the **negative electrode,** or **kathode.**

The process of decomposition by the electric current is called **electrolysis.**

2. Electrolysis of Water.

Experiment 2.

Arrange apparatus as shown in Fig. 246. The vessel is

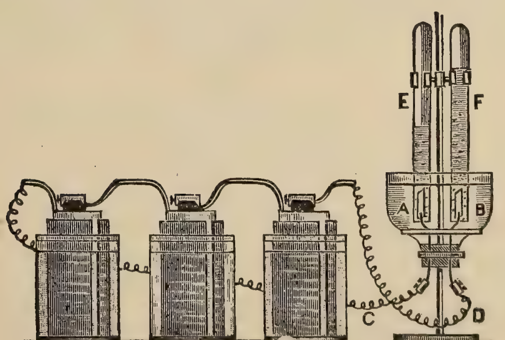


FIG. 246

partially filled with water acidulated with a few drops of sulphuric acid. The test-tubes E and F are also filled with

acidulated water and inverted over the plantinum strips A and B within the vessel. These strips are then connected by wires C and D with a battery of two or three cells, connected as shown.

1. Describe what takes place.

2. In what proportion by volume are the gases liberated ?

3. What is the source of the gases ?

3. Electrolysis of Salts.

Experiment 3.

Connect by means of two copper wires the poles of a battery with two platinum strips and dip them into a solution of copper sulphate. After two or three minutes remove them and observe the strips.

1. Upon which strip is there a deposit formed ?

2. What is the substance deposited ?

Without removing the deposit, place the strips again in the solution and then reverse the direction of the current by changing the wires at the poles of the battery.

1. Upon which electrode is the deposit now formed ?

2. Does the deposit remain on the plate which was at first the kathode ?

3. Is gas liberated at either electrode while the change in the deposit is taking place ? If not, explain.

Experiment 4.

Weigh two strips of copper, attach them respectively to the poles of a voltaic cell, and, without allowing them to touch, dip them into a solution of copper sulphate.

Is any change observed to take place at either plate ? If so, describe it.

When the strips have remained a few minutes in the solution, remove them, and, remembering which was the anode and which the kathode, weigh them again.

1. What change has taken place in the weight of (1) the anode, (2) the kathode?

2. How do you account for these changes?

4. Electroplating.

Experiment 5.

Connect by means of copper wires the positive pole of a battery with a clean strip of copper and the negative pole with a bright iron screw. Immerse the strip and the screw in a solution of copper sulphate (Fig. 247). When they have remained for a few minutes remove them.

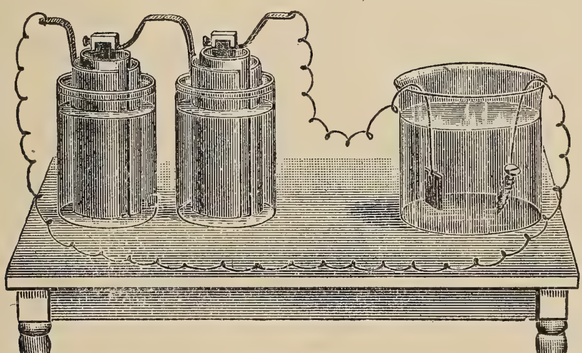


Fig. 247.

1. What is deposited on the screw?

2. What is the source of the deposit?

The deposition of a metal from a salt by means of an electric current is taken advantage of for covering one metal with a thin layer of another. The process is known as electroplating.

The metallic object to be plated is connected by a conductor with the negative pole of a battery or

dynamo, and immersed in a bath containing a solution of a salt of the metal with which it is to be plated. A plate of this metal is also immersed in the bath and is connected by a conductor with the positive pole of the battery or dynamo; that is, the object to be plated is made the kathode, the metal with which it is to be plated is made the anode, and the electrolyte is a salt of this metal. When the current passes through the solution from the plate to the object, the salt is decomposed and the metal is deposited on the object; but as the radical of the salt combines with the metal forming the anode, the strength of the solution remains constant. The metal is thus transferred from the plate to the object.

1. How could the electric current be made use of to remove the copper from the screw?

2. How may objects be plated with silver?

II.—Magnetic Effects.

5. Electro-Magnets.

We have already learned (Exp. 1, page 291) that an electric current deflects a magnetic needle. It has, therefore, apparently the power of producing magnetic effects. Let us investigate this subject.

Experiment 1.

Make a helix, or coil, of wire 3 or 4 inches long by winding insulated copper wire No. 20 around a lead pencil. Connect the ends of the wire to the poles of a battery, and place a magnetic needle in different positions with respect to the coil.

1. How does the magnetic needle set itself when placed (1) near each end of the spiral, (2) midway between the ends?

1. In what particulars does the helix resemble a bar-magnet?

3. Which pole of the helix is the observer in front of when the current in the coils facing him is passing in the direction of the hands of a clock?

4. Can the current in the coil be made to magnetize a piece of soft iron?

To answer the last question repeat Experiment 4, passing a small soft iron rod through the helix before the current is passed through the wire.

1. What effect has the introduction of the iron upon the magnetic power of the helix?

2. Are the N-seeking and S-seeking poles at the same ends of the helix as before the insertion of the core?

3. Will the end of the rod lift up a small piece of iron, such as a tack, (1) when the current is passing through the wire, (2) when the circuit is not completed?

A soft iron core surrounded by a helix of insulated wire, through which an electric current can be passed, is called an **electro-magnet.**

Why must the wire wound around the iron core be insulated?

Experiment 2.—To Make a More Powerful Electro-Magnet.

Take a round bar of soft iron one-half inch in diameter and cut off a piece two inches long. Turn down the ends of this piece for a distance of about one-quarter of an inch to three-eighths of an inch in diameter and fit tightly over each end a circular piece of fibre one and one-half inches in diameter,

thus forming a bobbin of the form shown in Fig. 248. The fibre can be kept in place by enlarging the iron at points in

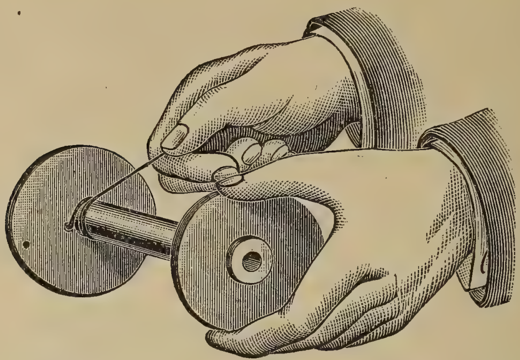


FIG. 248.

its circumference by marking it with a centre-punch at these points. Insulate the iron by wrapping it with a thin layer of insulating tape or manilla paper. Now bore a small hole through the fibre at one end just above the iron, pass the end of a piece of double covered magnet wire No. 20 through it as shown in the figure, and, by turning the bobbin, wind it nearly full of the wire as thread is wound on a spool, taking care that each layer is put on smoothly and evenly. When the bobbin is filled, cut off the wire and bring the end through another hole bored near the edge of the fibre as shown in Fig. 249.

FIG. 249.

For the experiments which are to follow have two such magnets made, winding the wire around each in the same direction. Try the power of the magnets by connecting them with a battery and using them to lift pieces of soft iron.

To make a still more powerful magnet connect the two magnets to a soft iron bar as shown in Fig. 250. This may be done by drilling a hole in one end of the core of each

and tapping[1] it to take the machine screw with which it is fastened to the bar, as shown in the figure. Connect the inner wire of the one magnet with the outer wire of the other so that the current in going through the wire may run in the proper directions around the core to form different poles at their free ends.

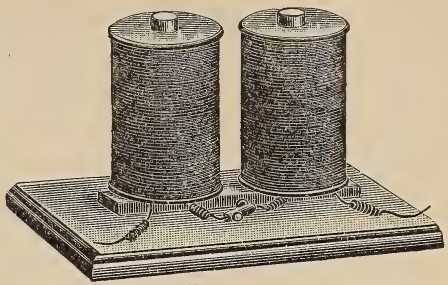


FIG. 250.

Connect the magnet thus formed with a battery, and try its power to lift pieces of soft iron.

Why should a magnet of this kind be more powerful than two separate magnets with the same current passing through them?

6. Uses of Electro-Magnets.

Electro-magnets are used in many of the important applications of electricity.

How May an Electro-Magnet be Used for Signalling?

Experiment 3.

Mount the horseshoe electro-magnet described above on a board by screwing the yoke to it and fit up the remainder of the apparatus shown in Fig. 251[2]. The beam A and support

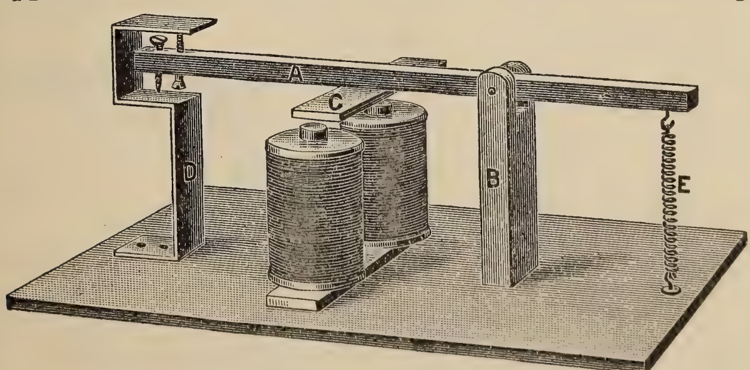


FIG. 251.

[1] A small hand drill and a small tap with machine screws to correspond should be a part of the equipment of every laboratory. No. 6, 32 is the most convenient size of machine screw. [2] For manual training exercise, see Appendix, page 332.

B are made of hard wood. The bar C is a thin piece of soft iron attached to the beam with wood screws. The frame D is made by folding hoop-iron into shape and screwing it to the board. The coil spring E should be made of fine piano wire. A thin rubber band may be substituted for it. The screws at the end of the bar should be so adjusted that the bar C at its highest position is one-eighth of an inch above the poles of the magnet and at its lowest almost in contact with them.

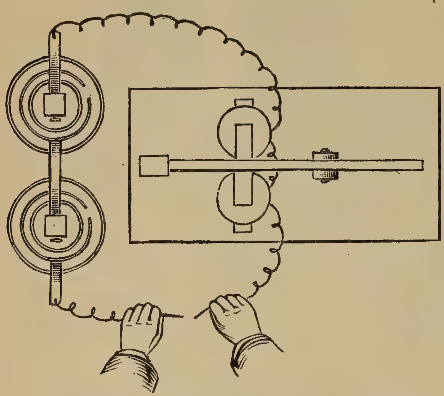


FIG. 252.

Connect the apparatus thus formed with a battery, leaving the circuit open as shown in Fig. 252. Close the circuit and then open it again by touching the wires together and then separating them.

1. What takes place?

2. How might this apparatus be used for the purpose of sending a signal?

Experiment 4.

Transform the apparatus described in the last experiment into an electric bell by substituting for the iron at the end a bell supported as shown in Fig. 253. The clapper is made by screwing a piece of iron or hard wood to one end of a piece of clock spring, the other end of which is attached by screws to the wooden beam A. The bell should be so placed that the clapper remains about one-sixteenth of an inch above the bell when the bar C is in contact with the poles of the magnet. Connect with a battery as in last experiment and try to use the bell for purposes of signalling.

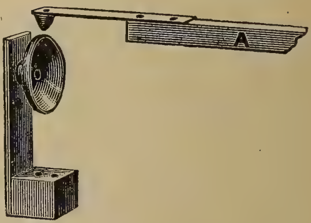


FIG. 253.

7. Electric Telegraph.

Experiment 3 illustrates the principle of the electric telegraph. Instead of closing and opening the circuit by touching the wires together, a **key** is used for this purpose.

Fig. 254 shows its construction. Two platinum contact points P, P, are connected with the binding posts A and B, the lower one being connected by a bolt C

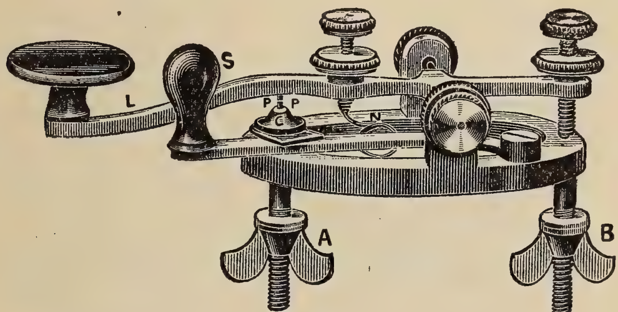


FIG. 254.

insulated from the frame, and the upper being mounted on the lever L which is connected with the binding post B by means of the frame. The key is placed in the circuit by connecting the ends of the wire to the binding posts.

When the lever is pressed down the platinum points are brought into contact and the circuit is completed. When the lever is not depressed a spring N keeps the points apart. A switch S, is used to connect the binding posts, and close the circuit when the instrument is not in use.

The apparatus constructed in Experiment 3 contains all the essential parts of the telegraphic **sounder**, which is used as the **receiver**.

Fig. 255 shows the construction of the sounder in common use. It consists of an electro-magnet, E, above the poles of which is a soft iron armature A mounted on a pivoted beam B, the beam being raised and the armature held by a spring S above the poles of the magnet at a distance regulated by the screws C and D. The ends of the wire of the magnet are connected with the binding posts.

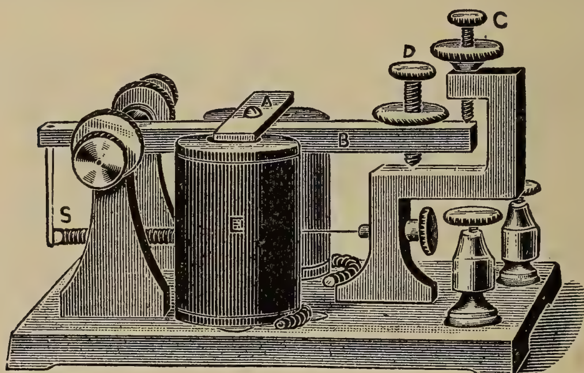


FIG. 255.

When the key and the sounder are connected in a circuit with the battery and the operator who is sending a message depresses the key and closes the circuit, the screw D of the sounder is drawn down against the frame, producing a click. When he breaks the circuit at the key, the beam of the sounder is drawn up by the spring against the screw C, producing another click. When the circuit is completed and broken quickly by the operator, the two clicks are very close together, and a "dot" is formed; but when an interval intervenes between the clicks the effect is called a "dash." Different combinations of "dots" and "dashes" form different letters. The operator is thus able to make himself understood by the listener.

8. Electric Bell.

Experiment 4 shows how an electro-magnet may be made use of in ringing a bell. The electric bells in common use are of various kinds. Fig. 256 shows the construction of one of the most common forms. It consists of an electro-magnet E, in front of the poles of which is supported an armature A by a spring S. At the end of the armature is attached a hammer H, placed in such a position that it will strike a bell B when the armature is drawn into the poles of the magnet. A current breaker, consisting of a platinum-tipped screw C in contact with a platinum-tipped spring D attached to the armature, is placed in the circuit as shown in the figure.

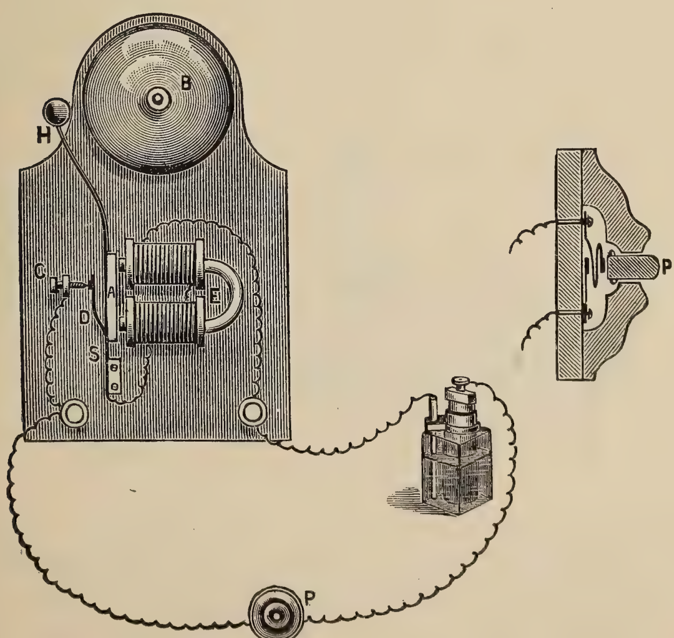


FIG. 256.

When the circuit is completed by a push-button P, the current from the battery passes from the screw C to spring D, through the electro-magnet and back to the battery. The armature is drawn in and the bell is struck by the hammer; but by the movement of the armature, the spring D is separated from the screw C, and the circuit is broken at this point. The magnet then releases the armature, the spring S causes the hammer to fall back into its original position, the circuit is again completed, and the action goes on as before. A continuous ringing is thus kept up.

9. Telephone.

Experiment 5.

Arrange apparatus as shown in Fig. 257. The iron rod has a coil of fine insulated wire wound around one end of it, and in front of this end is suspended a small soft iron disc. A battery is placed in the circuit with the coil, and the circuit is

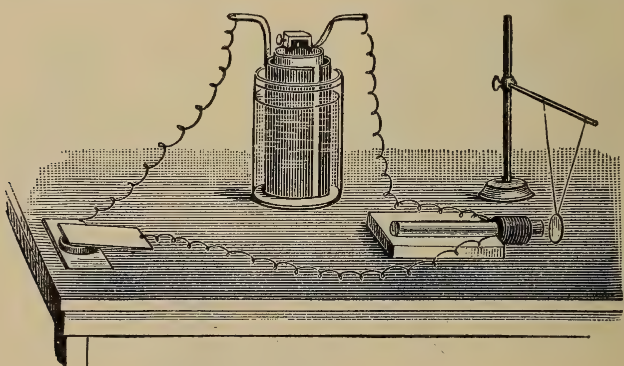


FIG. 257.

completed by attaching the wires to two small metal plates separated by a small wedge-shaped piece of graphite, or stove polish. Place the finger on the upper plate, and press upon it with different degrees of force.

Describe and explain the movements of the disc.

Experiment 5 illustrates the principle of action of the telephone.

Fig. 258 shows the working parts of the telephone now most commonly used.

The **transmitter** consists of a thin iron diaphragm D held against a small convex platinum button B, which is pressed by a highly polished carbon button A mounted in a piece of brass. The platinum and carbon buttons are supported by springs S, S^1.

The **receiver** consists of a magnetized steel rod near one end of which is wound a coil of fine insulated copper wire. In front of this end of the rod is supported a thin iron diaphragm D^1.

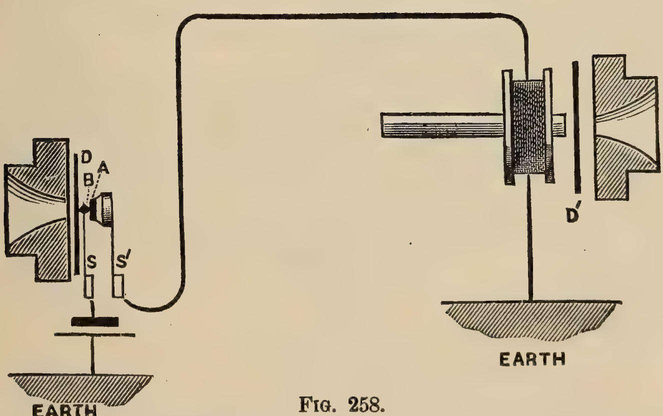


FIG. 258.

The receiver coil is connected by a wire with the carbon button, and the platinum button is connected with a battery. The earth usually forms the return current, as shown in the figure.

Sound-waves cause the diaphragm of the transmitter to vibrate. When it moves forward, the pressure between the platinum and carbon buttons is increased, and the resistance at this part of the circuit is decreased. The strength of the current passing through the coil of the receiver is consequently increased, and, as a result, the diaphragm of the receiver is drawn inward. When the diaphragm of the transmitter moves backward, the pressure between the buttons is decreased, the resistance is, therefore, increased, and the current in the circuit decreased. Through the decrease in current the magnet in the receiver loses some of its power, and the diaphragm in front of it springs backward.

Hence the vibrations of the diaphragm of the transmitter are accompanied by similar vibrations of the diaphragm of the receiver, which will reproduce the sound-waves which caused the diaphragm of the transmitter to vibrate.

III.—Heating Effect.

Experiment 1.

Repeat Experiment 6, page 189.

Whenever an electric current meets with resistance in a conductor heat results; and, as no body is a perfect conductor of electricity, a certain amount of the energy of the electric current is always transformed into the energy of molecular motion.

10. Practical Applications.

Resistance wires heated by an electric current are used for a variety of purposes, such as performing surgical operations, igniting fuses, cooking, heating electric cars, etc.

Rods of metal are welded by pressing them together with sufficient force while a strong current of electricity is passed through them. Heat is developed at the point of junction, where the resistance is the greatest, and the metals are softened and become welded together.

Experiment 2.

Connect the piece of fine iron or platinum wire used in Exp. 1 with copper wires leaving the circuit open, as shown in Fig. 259. Now embed the wire in one-half a teaspoonful

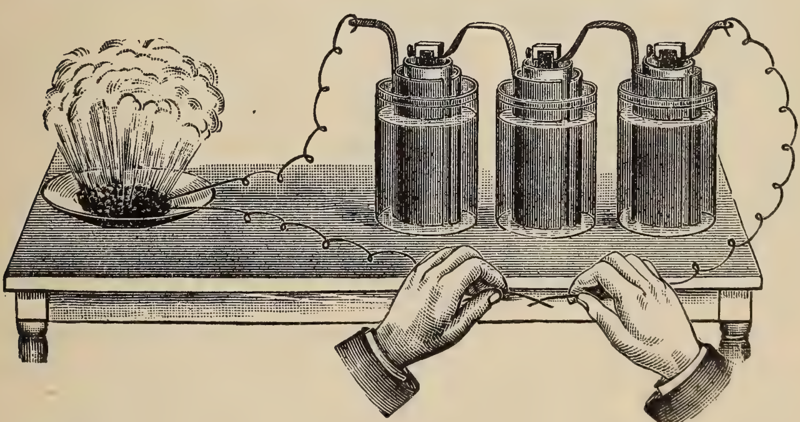


Fig. 259.

of gunpowder, being careful that no more powder is near by. Stand away from the gunpowder and close the circuit.

What is the result?

IV.—Lighting Effects.

11. Incandescent Lamp.

Experiment 1, page 318, illustrates the principle of the incandescent lamp. It consists essentially of a wire or filament kept at a white heat by an electric current passing through it.

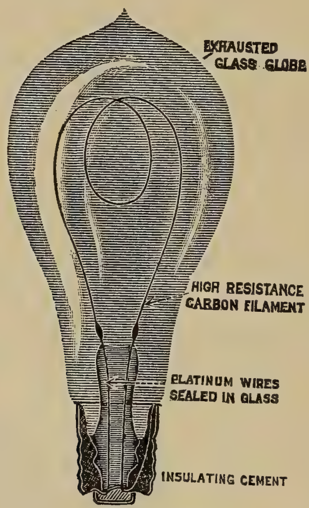


FIG. 260.

Fig. 260 shows the construction of a common form of the lamp. A carbon filament, made by carbonizing a thread of bamboo or other fibre at a very high temperature, is attached to conducting wires and enclosed in a pear-shaped glass globe, from which the air is then exhausted. The conducting wires are of platinum where they are fused into the glass.

When a sufficient current is passed through the high resistance carbon filament, it is heated to incandescence and yields a bright, steady light. The carbon is infusible, and does not burn for lack of oxygen to unite with it.

12. Arc Lamp.

Experiment 3.

Sharpen two small carbon pencils and connect them by means of copper wires to the poles of a battery, close the circuit by bringing the points of the carbons together loosely.

What is observed at the point of contact?

This experiment illustrates in a feeble way the principle of the **arc light.**

When two carbon rods, or pencils, are connected by conductors with the poles of a sufficiently powerful battery or dynamo, touched together, and then separated a short distance, the current continues to flow across the gap, developing intense heat and raising the terminals to incandescence, thus producing a powerful light (Fig. 261).

The arc lamp is provided with a regulator by which the carbons are kept at a constant distance apart.

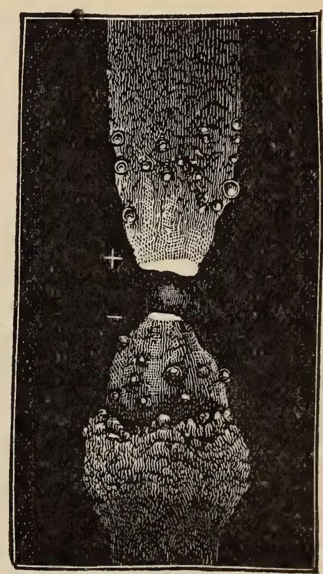


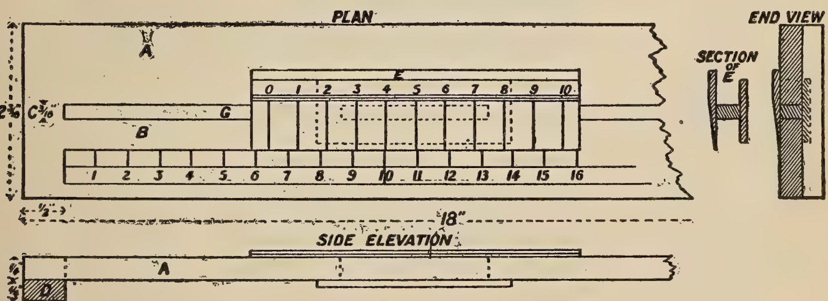
Fig. 261.

APPENDIX.

MANUAL TRAINING EXERCISES IN THE CONSTRUCTION OF APPARATUS REQUIRED IN THE TEXT.

1. Scale and Vernier.

The baseboard is made of two strips, A and B, separated by means of a $\frac{3}{16}''$ strip inserted at each end, as at C. Battens D are nailed across the under-side at each end.

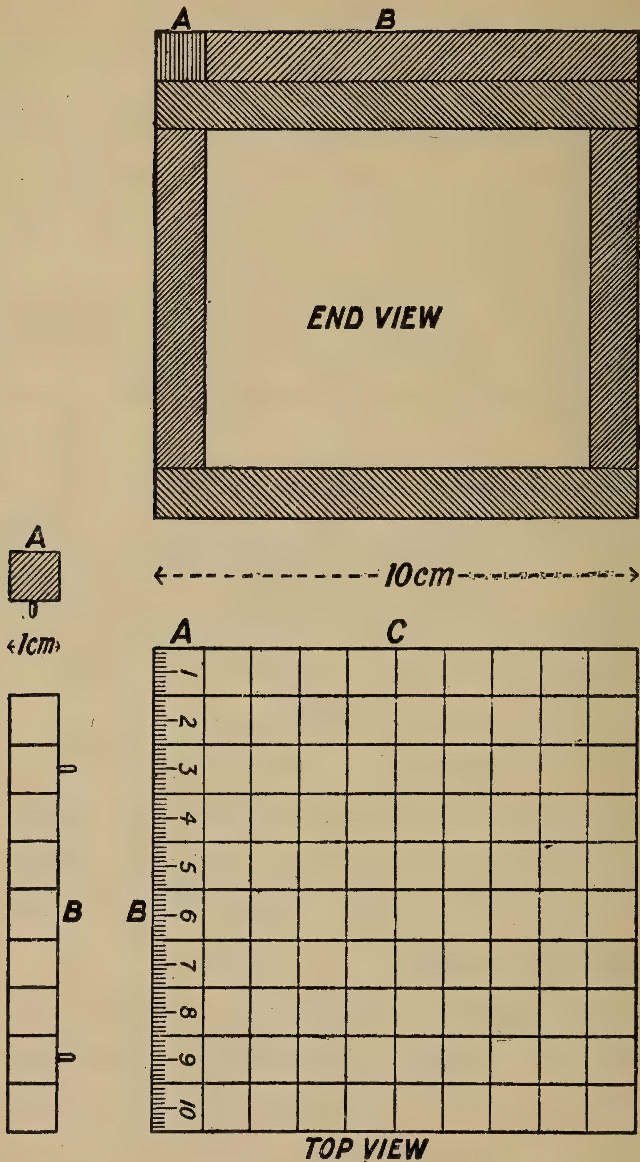


The sliding piece E is made of two thin strips joined by a strip the thickness of A and the width of the groove G; the upper piece is bevelled and graduated.

2. Dissected Litre Block.

Make a box 10 centimetres long, 10 wide and 9 deep, using wood 1 cm. thick. Make a second top piece about 11 cm. square and 1 cm. thick. Cut a strip B off one side, plane it to 1 cm. wide, and refit it to the larger side with dowels. From one end of piece B cut a piece A exactly 1 cm. square; dowel this to B, B to C, and the

whole to the top of the box, taking care to get the edge of B exactly in line with edge of box. Trim off the



remaining three edges to fit exactly with those of the box. Gauge lines as shown in drawing.

3. Balance.

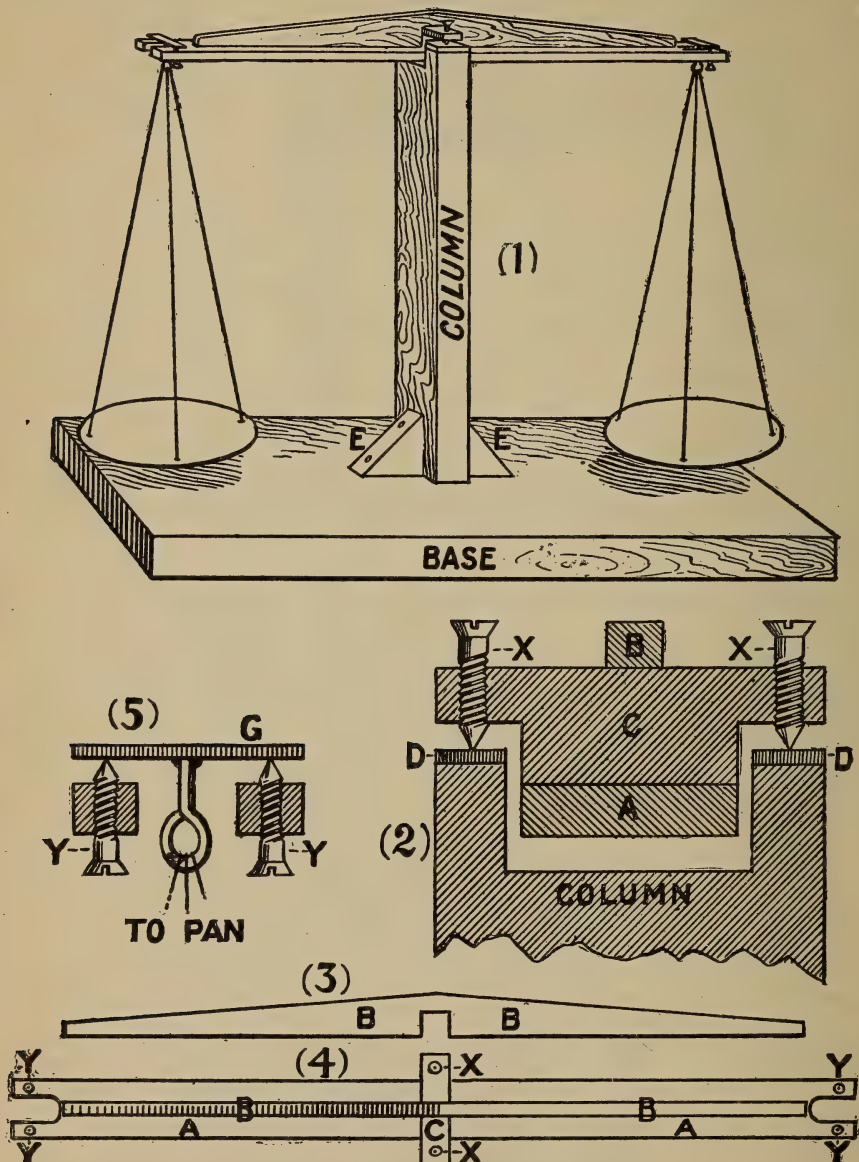
The home-made balance described below was devised by W. Lash Miller, Ph.D., F.R.S.C., Associate Professor of Physical Chemistry in the University of Toronto. It will be found useful in performing all experiments requiring a balance described in the text.

By permission of the University authorities the description is re-printed from Dr. Miller's work on "The New Requirements in Chemistry for Junior Matriculation and for the Departmental Examinations of the Province of Ontario," issued by authority of the University. It can be made for less than a dollar; and when carrying a kilogram on each arm, half a gram additional is enough to move the pans through three inches.

In the figure (1) shows the balance in perspective, (2) is a transverse section through the beam, column and screws which serve as "knife edges," (3) is the stiffening piece, (4) is a view of the beam from above, and (5) is a section through the beam near the end, to show how the pans are supported.

The base is a piece of board 8 × 30 inches. *The column* is of wood, 3 inches from front to back of (1), 1 inch from right to left, and 18 inches high, screwed to the base and supported by two triangular pieces E; a notch $\frac{5}{8}$ inch deep × $1\frac{3}{4}$ inches is cut out of the top, as shown in (2), and two small pieces of brass are screwed on at D. *The beam* is a lath, A, 25 inches long, $\frac{1}{4}$ inch thick and $1\frac{1}{2}$ inches wide, with a notch at each end $\frac{5}{8}$ inch wide and 1 inch long; it is stiffened by a vertical piece, B, of the same thickness, 23 inches long and 1 inch

high in the centre, tapering to both ends and fastened to A by screws. A transverse piece, C, of the shape shown



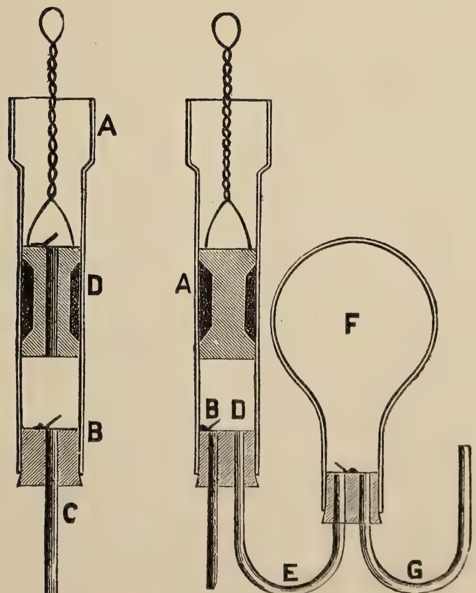
in (2) and (4) carries two screws, X (flat head bright, 1 inch No. 6), whose points are filed sharp and rock on the plates, D. Four more screws Y ($\frac{3}{4}$ inch No. 4), two

at each end of the beam, carry small pieces of brass, G ($1\frac{1}{2} \times \frac{3}{8}$ inches), to each of which is soldered a wire loop; *the pans*, of galvanized iron, $6\frac{1}{2}$ inches diameter, are hung from the loops by three strings each, so as to come about 3 inches above the base. Punch-marks may be made in the brass plates, G, to keep them from slipping off the screw points; the plates, D, should be left smooth.

The points of the six screws, X, Y, and the centre of gravity of the beam should be nearly in the same plane; the delicacy of the balance is increased by screwing down the two screws, X; if they are too low, however, the beam will overbalance on either side and will not rise. The balance should be adjusted once for all, best when weighted; a pointer with small adjustable weight may be added, if desired.

4. Pumps.

The following drawings give suggestions for con-

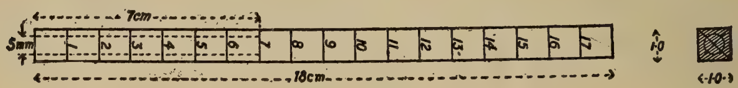


structing models of pumps. Lamp chimneys are used

for the barrels. The pistons are made by turning a block of wood to the form shown, and the packing is supplied by wrapping the pistons with a soft cord. The feed-pipes are pieces of glass tubing inserted into wooden blocks made to fit into the ends of the chimneys. The valves are made by tacking thin sheet-rubber to the wood. The air chamber for the force pump is a small Florence flask.

5. Hydrometer.

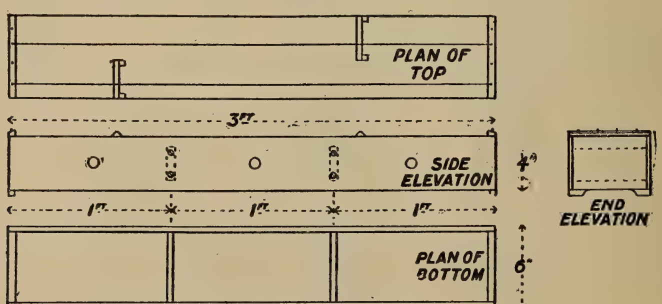
Plane a piece of straight-grained white pine, 20 centimetres long, 1 cm. wide, and 1 cm. thick. In one end bore a hole 7 cm. deep and 5 millimetres in diameter.



Square lines across one face of the wood 1 cm. apart and number the divisions, beginning at the hollow end.

6. Sonometer.

Use $\frac{3}{8}''$ clear white pine for sides, $\frac{3}{4}''$ for ends and braces, and $\frac{3}{16}''$ for top. Fix sides, ends and braces with

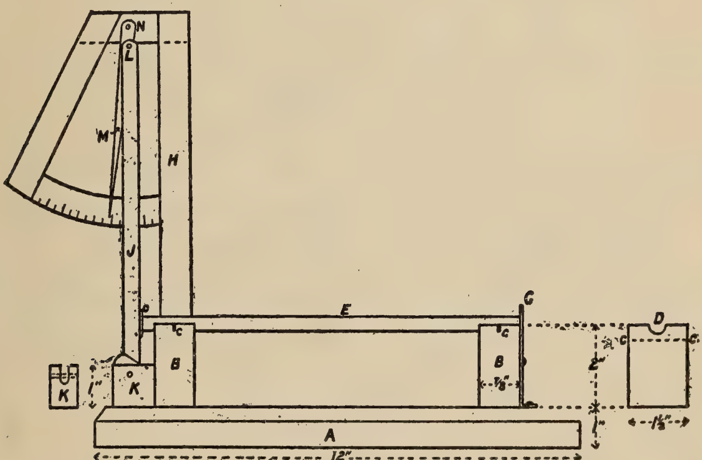


screws; glue top on. Use hard wood for bridges and end supports for the strings. The end supports must be

very firmly fixed to ends of box. Strong screws may be used for the string posts. A pulley should be attached to one end of the box so that weighted strings may be used.

7. Pyrometer.

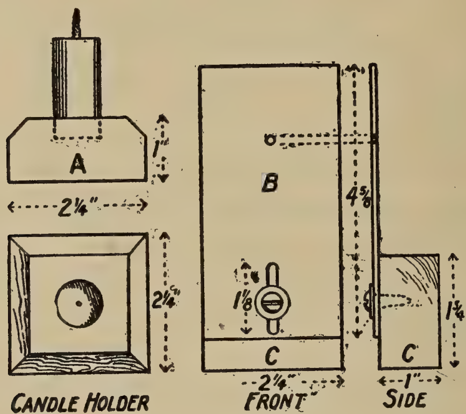
The base A is $12'' \times 5'' \times 1''$ with top edges bevelled. The uprights B are $2'' \times 1\frac{1}{2}'' \times \frac{7}{8}''$, and may be tenoned or screwed to the base. In the top edge a saw cut (*c*) is made and a strip of brass inserted. A groove D is filed in both brass and wood to carry the metal rod E. One end of this rod touches a brass plate G screwed to the



upright. The scale H is screwed to the other upright, and may be made of metal or very thin wood. The arm J is pivotted to the block K, and carries a projecting screw at L, which touches the edge of the pointer M, made to swing on a pivot N in the upper edge of the scale-frame. The distance from the rod to the pivot at K should be as small as possible. A small brass plate should be screwed to J at O.

8. Rectilinear Propagation of Light Apparatus.

Plane a piece of wood $11'' \times 2\frac{1}{4}'' \times 1''$. Cut a piece off one end $2\frac{1}{4}''$ long and bevel top edges for candle-holder A. Plane remainder of stick to $1\frac{3}{4}''$ wide and cut off 3 pieces, each $2\frac{1}{4}''$ long. Cut 3 strips of card-

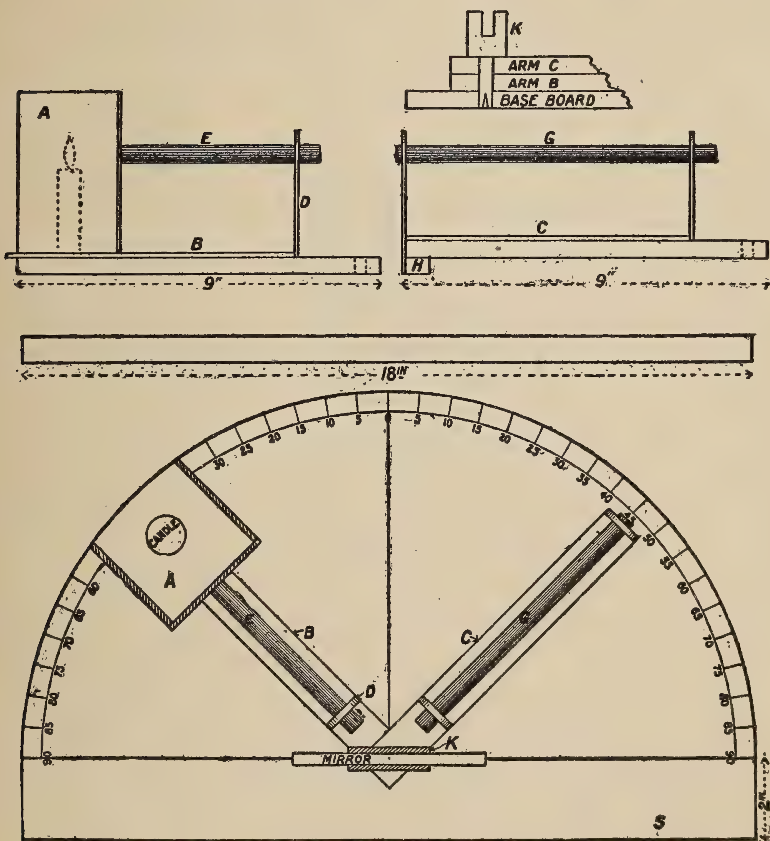


board or very thin wood $4\frac{5}{8}'' \times 2\frac{1}{4}''$. Punch holes in each piece about $1\frac{1}{4}''$ from top edge, midway between the sides. Near bottom edge cut a slot, wide enough to take a $\frac{1}{2}''$ screw, and about $1\frac{1}{8}''$ long. Fix the cardboard B to block C by means of screw and washer, and adjust to required height.

9. Reflection of Light Apparatus.

The base is a semi-circular board $18'' \times \frac{1}{2}''$ having a strip S tongued and grooved to the straight-edge. The curved edge of base is graduated in degrees. B is an arm carrying an open box A containing a candle, and a support D for holding the glass tube E. C is another arm supporting the tube G. This arm fits over arm B and is made level by having a block H glued to one end, corresponding in height to the thickness of B. Both the

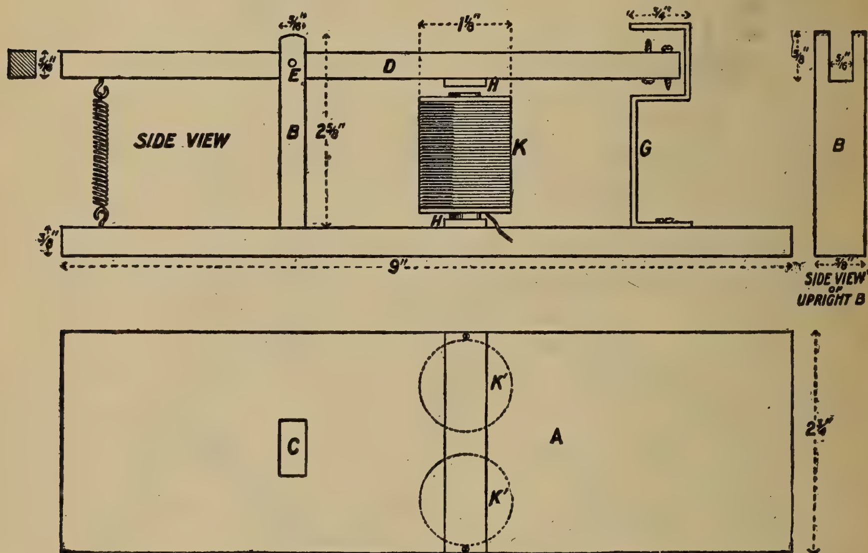
arms are pivoted at one end on the stem of the mirror-holder K. The mirror is fitted into a groove and the stem is made round and passes through holes in arms B and C and the base, being firmly glued and wedged to the latter. The mirror must be exactly at right angles



to a line from the centre of the hole to the zero mark on edge of base. The two glass tubes should be painted black and must be fixed at exactly the same height above the baseboard and parallel with it. A vertical line should be drawn on the base of each arm directly under the centre of the tubes.

10. Sounder and Bell.

The base A is made of hard wood, top edges bevelled or rounded. The upright B is tenoned into base A at C, and carries the arm D working on a pivot in the groove at E. At one end of D is a coiled spring, and at the other two projecting screws pointing in opposite directions. G is made of soft brass or hoop-iron, bent to the



required shape and screwed to the base. H H are two iron plates, long enough and wide enough to cover the cores of the two magnets K, placed side by side as shown by the dotted circles K′ K′. The upper iron plate is screwed to the under-side of the bar D; the magnets are screwed to the lower one, which in turn is fixed to the base.

INDEX.

The references are to pages.

148